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ELECTRICAL INSULATION FIRE CHARACTERISTICS
Volume II: Toxicity

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Oklahoma City OK 73125

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Transportation
Systems Center

NOTICE

The animals used for this experiment were lawfully acquired and treated in accordance with the "Guide for the Care and Use of Laboratory Animals" prepared by the Committee on Revision of the Guide for Laboratory Animal Facilities and Care of the Institute of Laboratory Animal Resources, National Research Council, DHEW Publication No. (NIH) 74-23.

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16. Abstract

The relative toxicities of the combustion products of 14 electrical wiring insulations were evaluated using animal incapacitation as a measure of toxicity. One-gram insulation samples were pyrolyzed in a quartz combustion tube connected in-line with a 12.6-L-exposure chamber by an air recirculation assembly to form a closed exposure system. Each material was pyrolyzed under three thermal degradation conditions and the time-to-incapacitation for the "worst case" condition (shortest time) was used to rank the materials in order of their relative potential toxicity. A rank order for all 14 materials is presented on the basis of potential toxicity for equal weights of insulation; relative ranking by toxicity for equal lengths of conductor is presented for those materials supplied on conductors of equal gauge. Techniques are suggested for converting measured toxicity of an insulation on wire of one size to the equivalent toxicity of the same insulation on wire of a different size.

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PREFACE

This report describes the results of a study of the relative toxicities of the gaseous pyrolysis products of certain electrical wiring insulations. The study was conducted by the Aviation Toxicology Laboratory at the FAA Civil Aeromedical Institute (CAMI). The project was funded by the Department of Transportation, Urban Mass Transportation Administration (UMTA), and the program was initiated and monitored by the Transportation Systems Center (TSC). The insulation specimens were selected from a larger group of candidate materials in a study of fire-related properties, other than toxicity, performed by the Boeing Commercial Airplane Company and described in Volume I of this report. The work herein was performed between July 1977 and March 1978. It consists of test design criteria, animal response data, and a relative ranking of 14 insulation materials on the basis of the relative inhalation toxicity of their thermal degradation products.

The authors would like to acknowledge the assistance provided by G. D. Hanneman, D.V.M., J. L. Sershon, F. W. Fore, and C. H. Shoals for experimental animal maintenance and handling. Special acknowledgment is also made to I. Litant, TSC Technical Monitor, for his advice and guidance throughout this project.

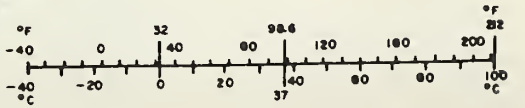
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inchss	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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SYMBOLS AND ABBREVIATIONS

t_o	Time zero, the time at which thermal degradation of the insulation sample is initiated.
t_r	Time-to-response, the time elapsed between t_o and animal response; responses recorded in this study were incapacitation and death.
t_i	Time-to-incapacitation, the time elapsed between t_o and animal incapacitation, i.e., when the animal can no longer perform the coordinated act of walking in the rotating cage.
t_d	Time-to-death, the time elapsed between t_o and the time when visible signs of breathing cease in the experimental animal.
Obs t_r	Observed time-to-response, the time elapsed between t_o and the experimental observation of animal response.
Std t_r	Standard time-to-response, the Obs t_r corrected for the deviation between the animal weight and 200 g, and for the deviation, if any, between the sample weight and 1 g. It is the Obs t_r normalized to the response of a 200-g rat to a 1-g sample size.
Loss t_r	Loss time-to-response, the theoretical response time for a 200-g rat exposed to the gases from a sample of sufficient weight to produce a sample weight loss of exactly 1 g.
t_r'	Calculated t_r (in minutes) for a 200-g rat exposed to the gases produced from the insulation on 1 meter of conductor.
O.D.	Optical Density (Absorbance), the logarithm to the base 10 of the ratio of incident light intensity divided by transmitted light intensity.
LTNF	Low temperature, nonflaming condition.
LTF	Low temperature, flaming condition.
HTF	High temperature, flaming condition.
CO	Chemical symbol for carbon monoxide.
HCN	Chemical symbol for hydrogen cyanide.
H_2S	Chemical symbol for hydrogen sulfide.
AWG	American Wire Gauge

ELECTRICAL INSULATION FIRE CHARACTERISTICS, VOLUME II: TOXICITY

EXECUTIVE SUMMARY

INTRODUCTION

Over the past decade there has been an increased general awareness of the potential toxic hazard associated with the thermal degradation of all polymeric materials. This general concern on the part of industry, the public, and government has fostered considerable research directed toward the evaluation of the relative merits of polymeric materials in current use, as well as toward the manufacture of new materials with improved "fire hazard" properties.

This same period of time has seen an increased growth in the rapid transit industry with correspondingly increased usage of electrical wire and cable insulation material. The industry, therefore, has an immediate and urgent need for reliable test procedures with which the relative fire-related properties of both old and new insulating materials can be assessed.

The Urban Mass Transportation Administration (UMTA), which now has total DOT program responsibility for safety in rapid rail and light rail transit systems, sponsored the research reported in this volume in an effort to insure the least possible delay in providing the information and technology necessary for industry to identify reasonably safe materials.

There are many properties of a material that relate to its performance and potential safety hazard in a fire environment. Investigation of those pertinent properties other than toxicity, and techniques for their measurement, are the subject of Volume I, Electrical Insulation Fire Characteristics, which represents research conducted by the Boeing Commercial Airplane Company, Seattle, Washington, under Contract DOT/TSC-1221. In that study 104 specimens of insulation were evaluated, of which 83 were single-conductor specimens and 21 were multiple-conductor assemblies with representation from both the current-usage and new, state-of-the-art categories.

Fourteen of these subject materials were selected for evaluation of the relative toxic potentials of their volatile thermal degradation products, a potential hazard for passengers in the limited confines of a rapid transit vehicle or subway tunnel. This research was conducted at the Civil Aeromedical Institute, FAA, and is the subject of Electrical Insulation Fire Characteristics, Volume II: Toxicity (Contract No. DOT-TSC-RA 77-15, RA 77-16).

METHOD

Insulation samples were pyrolyzed in a quartz combustion tube through which air from the animal exposure chamber was circulated, forcing the smoke/gases into the chamber and forming a closed system. Male albino rats were confined in circular, motor-driven, rotating cages within the exposure chamber, forcing them to walk in order to maintain an upright position. The elapsed time between initiation of sample pyrolysis and the time when the rat could no longer perform the coordinated act of walking was recorded as observed time-to-incapacitation (Obs t_i). When all rats were incapacitated, cage rotation was stopped and the rats were observed until visible signs of breathing ceased. The elapsed time between pyrolysis initiation and cessation of breathing was recorded as observed time-to-death (Obs t_d). Rats surviving the 30-minute observation period were removed from the exposure chamber and held for 2 weeks to observe any delayed toxic effects.

It is currently impossible to accurately predict how the toxicity of the resultant gas mixture from a given material will vary with different thermal degradation conditions. Therefore, each insulation was decomposed at two temperatures, both of which could be realistically expected to occur in an actual fire, and under flaming and nonflaming conditions. Time-to-incapacitation for the "worst case" (shortest t_i) thermal condition for each material was selected as the physiological endpoint for ranking the relative toxic potential of the materials. The authors consider ranking on the basis of t_i to be more realistic than ranking by t_d since potential victims in a developing fire situation usually must remove themselves from the fire environment or perish in it. Also, physical incapacitation normally occurs much earlier than death (but with no constant t_d/t_i ratio), and a ranking based on t_d might significantly misrepresent the relative threat posed by the different insulations.

RESULTS

A rank order for all 14 materials, in terms of their relative potential toxicities, and based on equal weights of materials, is shown in Table S-1. This rank order is based on the standard t_i, in minutes, and is arranged in order from rank 1 (least toxic) to rank 14 (most toxic).

The standard t_i's in Table S-1 reflect the potential toxicities for equal weights of the insulation materials and represent the starting points for calculating the <u>end-use</u> relative toxicities when the total weights of the materials in the end-use application are known.

TABLE S-1. MATERIAL RANK-ORDER BASED ON WORST CASE PERFORMANCE FOR STANDARD t_i

Rank	Material No.		Mean Std t_i*
1	A6-4X12-1	(Sil/Glass Braid)	22.0†
2	1-16-1	(Silicone/PO)	17.9
3	A7-24X19-5	(PE/Al/PVC/Grease)	7.5
4	A1-14-1	(PVC)	7.4
5	A5-00-3	(PE/Cu Shield)	7.4
6	A7-00-2	(EPR/Neoprene)	7.3
7	11-20-1	(Exane)	7.0
8	A2-6/2X19-4	(PE/Cu Shield)	6.9
9	12-20-2	(Teflon)	6.7
10	A5-14-1	(EPR/Hypalon)	6.6
11	A3-7X14-2	(Prop/Cloth/Neoprene)	6.0
12	12-12-4	(Halar)	4.7
13	3-20-1	(Tefzel)	4.5
14	13-16-1	(Kapton)	4.5

*Standard t_i is the observed t_i normalized to a standard rat weight of 200 g. Mean values are for nine animals unless otherwise noted.

†N = 8; one animal did not incapacitate in 30 min.

CAUTIONS AND LIMITATIONS

Data in this report were derived by a protocol that has been used to evaluate approximately 200 polymeric materials and the authors have little concern over repeatability of reported results, or interpretations, as applied to this system. At present, however, little scientifically demonstrated evidence exists indicating that laboratory-scale tests can successfully predict the toxic behavior of a material in a real fire. Test protocols developed by other laboratories have assigned significantly different relative toxicities to the same materials, leading to the inescapable conclusion that caution must always be used in relating data from laboratory tests to any frame of reference other than that from which the data originated. It is especially important to realize that the relative merit assigned to materials by these tests could be entirely different from their relative merit based on behavior in an uncontrolled, full-scale fire.

INTRODUCTION

The purpose of this research was to determine the relative inhalation toxicity of the thermal degradation products of selected types of electrical insulation. The specific materials to be evaluated were supplied by The Boeing Commercial Airplane Company and were selected from a much larger population on the basis of prior testing of properties other than toxicity. These prior tests were conducted by Boeing under Contract DOT-TSC-1221 and are described in their report, "Electrical Insulation Fire Characteristics, Volume I."

The contract work-statement required that toxicity be evaluated utilizing the basic principles of a system designed at the Civil Aeromedical Institute (CAMI) that was used for an earlier study of aircraft interior materials (1). The thermal test parameters were to be established experimentally and were to include a minimum of two decomposition temperatures, as well as a flaming and nonflaming mode. Each condition was to be replicated three times, using three animals per replication, with the time-to-incapacitation and time-to-death recorded for each animal. The maximal exposure time was to be 30 minutes.

The final requirement was for a systematic and objective protocol for converting the experimentally measured animal response times to a rank-order-listing of the test materials that would reflect the relative toxic potential of their volatile combustion products.

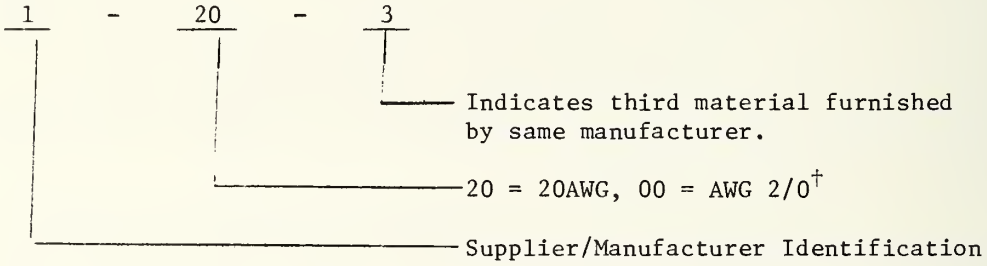
---

(1) Crane, C. R., D. C. Sanders, B. R. Endecott, J. K. Abbott, and P. W. Smith: Inhalation Toxicology: I. Design of a Small-Animal Test System. II. Determination of the Relative Toxic Hazards of 75 Aircraft Cabin Materials, Office of Aviation Medicine Report No. FAA-AM-77-9, 1977. (Document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.)

METHODOLOGY

MATERIAL DESCRIPTION

The 14 test specimens, as received from Boeing*, had each been assigned a three-unit identification number during the Boeing tests; these same identification numbers are used throughout this report. The identification scheme utilizes three groups of digits to designate the wire manufacturer, wire gauge, and the number of samples submitted by that particular manufacturer, as shown below.


1 - 20 - 3
Indicates third material furnished by same manufacturer.
20 = 20AWG, 00 = AWG 2/0†
Supplier/Manufacturer Identification

†For multiconductor cables, this number was written 7X12; the 7X indicates 7 individual insulated conductors; the 12 indicates that each conductor was a 12AWG wire.

A physical description of the pertinent properties of each conductor and its insulation, as measured in the CAMI laboratory, is presented in Table 1; additional descriptive data, furnished by Boeing, is presented in Table 1A. Cross-sectional drawings of the more complex multicomponent materials are shown in Figures 1-8.

SYSTEM DESIGN

The system used to rank the toxicity of combustion products from 75 aircraft cabin interior materials (1) was modified for testing the electrical conductor insulations. The animal exposure chamber, temperature monitoring, and recirculation assemblies were unchanged; modifications were made only on the furnace-combustion tube assembly.

*The Boeing Commercial Airplane Company, Seattle, Washington

The requirement that the materials be tested in both flaming and non-flaming modes necessitated (i) the design of a reliable ignition device and (ii) the use of a larger diameter combustion tube. The larger tube decreased the linear velocity of the evolved gases in the vicinity of the igniter and allowed a flammable gas concentration to occur. It also provided a larger mass of diffusible oxygen in the vicinity of the thermal degradation zone.

The final combustion-exposure assembly is shown in Figure 9. The modified combustion tube consisted of a 2-inch-diameter section, 13 inches long, connected to an 11-inch-long, 1-inch-diameter section by a 2.5-inch-long tapered segment. The combustion tube was quartz (Vycor). Total enclosed volume was 12.6 liters.

Sample heating was accomplished with two semicylindrical resistive heating elements (Aten, Ltd.)* that were fitted around the combustion tube (see Figure 9 insert) and secured with metal bands. (We found that, even though the heaters encircled the sample, flame initiation could be observed from the chamber end of the furnace.) A thermocouple embedded in the lower heating element was calibrated against a thermocouple in the sample position to provide a reference point for controlling the furnace temperature.

Ignition of the gases evolved from heated samples was accomplished with the spark igniter shown diagramatically in Figure 10. The igniter consisted of a pair of stainless steel wires sandwiched between polymethylmethacrylate (PMMA) plates and extended down the center of the combustion tube. These wires projected at a slight downward angle over the downstream end of the combustion boat. The exterior conductors were attached to an automotive coil-capacitive discharge ignition unit that produced a high-intensity spark between the nodes of the wire electrodes and ignited the evolved gases. Combustion boats for containing the insulation samples were constructed from split sections of 1 5/8-inch quartz tubing, 3 inches long, with the ends partially closed to prevent melted sample material from running into the unheated area of the combustion tube.

Relative smoke densities were measured with a smoke detector mounted on the recirculation tube assembly between the blower outlet and the flow restrictor. The detector consisted of a photodiode behind a Wrattan #25 filter, and was mounted across the tube from a 6 VDC tungsten lamp. The light path was 24 mm. The instrument was calibrated with neutral density filters and the results (Appendices A and B) are reported in optical density units (OD). The relative performances among materials, and among the various thermal modes, can be evaluated from the OD values reported in those tables. OD for a 1-meter light path may be calculated by multiplying OD_{24mm} (from tables) by (41.7).

---

*Aten, Ltd., has since been acquired by:
Watlow Electric Mfg. Co.
12001 Lackland Road
St. Louis, Missouri 63141

SAMPLE PREPARATION

Insulation was removed from the single-conductor specimens in pieces that were 1 cm to 4 cm long using a Stripmaster, model C, manual wire stripper (Ideal Industries, Inc., Sycamore, Illinois). These pieces were conditioned for a minimum of 24 hours in a constant humidity chamber (50% $\pm$ 2% relative humidity), then cut into approximately 1-cm lengths, and the required sample weights were weighed to the nearest 0.01 mg.

The diameters and complexities of the multiple-conductor and composite insulations required that a different sampling technique be used. (Several materials were of such a diameter that a 1-gram sample of insulation represented a cross section that was only about 0.15 cm in length.) Therefore, a long (28-30 cm) piece of each composite wiring was weighed, measured, and dissected to determine the weight of each component, and a 1-g composite aliquot was prepared in which the weight of each component was proportional to its percent of the total insulation weight. All components were conditioned prior to weighing, as previously described; individual component pieces were cut no larger than 1 cm^2 with the thickness equal to that of the particular component layer.

The weighed and conditioned pieces were placed in the rear third of the combustion boat (3 in long x 1½ in dia) with the longitudinal axis of the insulation pieces parallel to the length of the boat. With most materials, a single layer of insulation was achieved with all pieces touching the sides/bottom of the combustion boat, but with the thin-layered insulations, Kapton and Tefzel, a partial second layer was necessary to obtain a 1-gram sample.

When the combustion boat was pushed into the heated tube with a graduated metal rod, the center of the 1-in segment containing the sample was centered in the hottest part of the furnace.

SAMPLE WEIGHT

We found experimentally (see tables in Appendix B) that a minimum sample weight of 1.00 gram was required to insure obtaining response times within the 30-minute limit prescribed for the test procedure. Therefore, all materials were tested at this sample weight, which corresponds to a fuel load of 80 mg fuel per liter of enclosed space.

TEST PROCEDURE

Animal selection, fasting, and the general test procedure were essentially identical to those described previously (1). Briefly, the procedure was as follows.

Male rats (100-120 g), Sprague-Dawley derived, were procured from Charles River Breeding Laboratories*. They were held in isolation with 10-12 animals/cage, for 10-14 days, and for the first 7 days an antibiotic (sulfathiazole) was added to the drinking water. All food and water was removed the afternoon prior to the day of the test. Randomly selected animals were weighed and marked with an identifying color code. All survivors of each experiment were returned to cages where they were weighed and observed daily for 14 days, or until they expired. A summary of animal mortality for all test conditions is presented in Appendix C.

The combustion tube was preheated to the desired temperature prior to insertion of the test specimen. Immediately on insertion of the sample boat, the recirculation tube was closed; the mixing fans and recirculation blower were turned on; cage rotation was started; thermocouple recorder, analytical systems and master timer were activated simultaneously. The chamber atmosphere was continuously recirculated through the combustion tube at a rate of 4 L/min.

Oxygen concentration in the exposure system was monitored gas chromatographically and maintained above 19 percent (vol/vol, absolute) by manual addition of O_2 as needed. For samples burned in the flaming mode, the igniter was turned on from the initiation of the test until ignition occurred; it was then turned off to prevent unnecessary ozone formation and to minimize electrical disturbance of the recording apparatus.

EXPERIMENTAL DATA COLLECTION

The following measurements and observations were recorded during the course of each experiment.

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(1) Crane, C. R., D. C. Sanders, B. R. Endecott, J. K. Abbott, and P. W. Smith: Inhalation Toxicology: I. Design of a Small-Animal Test System II. Determination of the Relative Toxic Hazards of 75 Aircraft Cabin Materials, Office of Aviation Medicine Report No. FAA-AM-77-9, 1977. (Available to the public through the National Technical Information Service, Springfield, Virginia 22161.)

* Charles River Breeding Laboratories, Wilmington, Massachusetts.

Animal Responses

Time-to-incapacitation, t_i, was measured in minutes of elapsed time from initiation of thermal degradation (t_o) until the subject no longer exhibited coordinated physical activity in the rotating cage; i.e., until tumbling began.

Time-to-death, t_d, was measured in minutes from t_o until there were no visible signs of respiration.

Smoke Production

The output of the smoke detector was recorded continuously on a strip-chart recorder as a function of time. Three specific items of information from this record were entered into the data log for each experiment; namely, the time at which smoke was first detected, the time(s) at which smoke density peaked, and the magnitude of this maximum smoke density (OD).

Flaming Ignition

The time at which visible flames were first noted, and the time at which they went out, were recorded manually.

Chamber Air Temperature

The temperature was monitored with thermocouples from eight locations in the chamber and recorded throughout the experiment on a multipoint strip chart recorder. The design protocol was such that chamber temperature never exceeded 35°C during an experiment, but the thermocouples provided verification of this during an experiment and also reflected the speed and adequacy of air mixing in the dynamic system.

Gas Analyses

A continuous stream of air was pumped from the chamber, via 1/8" Saran tubing, through gas chromatographic sample loops and back into the exposure chamber. At approximately 1.8-min intervals a gas chromatograph (GC) sampled this flowing stream. Carbon monoxide and oxygen were measured by this procedure throughout the experiment. Although a second GC was normally a part of the system and was used to measure chamber cyanide, it was not functional during the tests reported here.

Sample Weight Loss

At 10 min the recirculation blower was shut off, the combustion assembly was disconnected from the chamber, and the chamber outlets were sealed. The sample boat was removed from the furnace, cooled, and reweighed.

The original sample weight minus this residual weight yielded the nominal weight of material lost during the decomposition. Observation continued until the third animal died or until 30 min had elapsed.

DATA NORMALIZATION PROCEDURES

Animal response times, as measured experimentally, are referred to as observed (Obs) response times. Corrected response times that take into account the deviation of an animal's body weight from 200 g are referred to as standard (Std) response times for a 1.0-g sample size. Observed times are converted to standard response times as follows (1):

$$\text{Std } t_r = \text{Obs } t_r \cdot (200 \text{ g/body wt, g})^{0.25}.$$

Loss t_r calculates a theoretical Std t_r for the case in which sufficient weight of sample is placed in the furnace to produce a loss in sample weight of exactly 1.0 g. This conversion is accomplished as follows (1):

$$\text{Loss } t_r = \text{Std } t_r \left[\frac{\text{Wt sample lost}}{\text{Wt sample}} \right].$$

PRELIMINARY TESTS

The state-of-the-art in combustion toxicology is such that one cannot predict at this time how the toxicity of the resultant gas mixture will vary with the conditions of the thermal degradation. For these tests, therefore, it was felt that a minimum of two temperatures should be used, and those temperatures should be ones that could be realistically expected to occur in actual fires. In addition, it was felt that one temperature should produce rapid thermal decomposition but not produce spontaneous flaming, and the second test temperature should produce flaming combustion, either spontaneous or induced by electric spark.

During preliminary testing, we sought (i) to identify a temperature for each material that would produce essentially complete decomposition of all polymeric material within a 10-minute period, but would be below the autoignition temperature for the evolved gases and for the material; (ii) a minimum temperature at which ignition could be reliably attained using the electric arc; and (iii) a high temperature at which all materials decomposed rapidly, with or without autoignition. These three conditions will hereafter be referred to as low temperature nonflaming (LTNF), low temperature flaming (LTF), and high temperature flaming (HTF), respectively.

We considered it desirable to perform the two low temperature studies at a single temperature in order to better study the effects of flaming versus nonflaming combustion, with all other parameters held constant. We were able to satisfy this requirement for all materials except #12-12-4 (Halar), which required a minimum decomposition temperature of 750°C to produce an ignitable atmosphere.

RESULTS AND DISCUSSION

PRELIMINARY EXPERIMENTS

The results of the exploratory tests for each material are summarized below and identified by Boeing's I.D. number; all of the preliminary data are presented in tables in Appendix B.

11-20-1

Exane decomposed at 550°C without spontaneous ignition but flamed readily at that temperature when ignited with the electric spark. Spontaneous flaming was first noted at 600°C and occurred consistently at the 750°C high temperature condition. Sample weight loss was 80-85 percent over the 550°-750°C range. The sample residue consisted of a light-yellow granular material that tended to stick to the quartz combustion boat and that required the application of steel wool for its removal. A temperature of 550°C was selected for the low temperature flaming and nonflaming tests, and 750°C was selected for the high temperature flaming test.

12-12-4

Under our experimental conditions, Halar decomposed readily at 550°C with a 100-percent sample weight loss and with the evolution of relatively large quantities of grayish-white "smoke." Ignition of these gaseous products proved difficult, however, despite their rapid generation rate. Small spheres of burning gases were observed (2-3 mm dia) around the igniter spark, but we were unable to achieve reliable ignition, with self-sustaining combustion, below 750°C. The low temperature nonflaming tests for this material were performed at 600°C; the "low" temperature (flaming) and the high temperature tests were performed at 750°C. Halar and composite A5-14-1 were the only insulation materials in this series that did not flame spontaneously at 750°C.

13-16-1

Decomposition products from Kapton could not be ignited reliably at temperatures below 650°C. This material proved to be very heat stable as indicated by a sample weight loss in 10 minutes of only 40 percent at 550°C, and 93 percent at 850°C. A compromise temperature of 650°C was selected for the low temperature studies, which allowed selective flaming and nonflaming combustions with sample weight losses of 60-72 percent during the 10-minute heating period. Kapton flamed spontaneously at 750°C and at 850°C.

1-16-1

Silicone rubber/polyolefin left a considerable amount (approximately 60 percent) of residue that did not volatilize even at the highest temperature. Sample weight loss was essentially the same (38-40 percent) over the temperature range 550°-750°C, and reliable ignition of the combustion products was obtained at 550°C with the spark igniter. Spontaneous ignition of the sample began at 600°C and always occurred at the high temperature (750°C). A furnace temperature of 550°C was selected for the low temperature flaming and nonflaming tests.

12-20-2

The Teflon insulation decomposed (94-100 percent) in less than 10 minutes at 550°C, but the decomposition products could not be ignited at that temperature. Subsequent attempts to ignite the decomposition products also failed at temperatures of 575°C, 600°C, and 625°C. At 700°C, however, the Teflon ignited spontaneously. A temperature of 650°C allowed us to obtain both flaming (with spark-induced ignition) and nonflaming (without spark) combustion at the same furnace temperature. At the high temperature (750°C), Teflon flamed spontaneously in each test.

3-20-1

This Tefzel/polyimide insulation material decomposed at 550°C with 86-94 percent sample weight loss in 10 minutes and with a decomposition rate sufficient to allow ignition of the gaseous products with the spark igniter. Spontaneous ignition occurred at the high temperature (750°C).

A1-14-1

Irradiated polyvinylchloride decomposed readily at 550°C without autoignition but flamed at that temperature when ignited by the electric spark. Spontaneous ignition occurred at 750°C. Sample weight loss was 89-90 percent at 550°C, and 91 percent at 750°C. A furnace temperature of 550°C was selected for the low temperature flaming and nonflaming tests.

A7-00-2

This EPR/Neoprene insulation failed to autoignite at 550°C but flamed spontaneously at 750°C. Ignition of the gaseous products was obtained at 550°C with the spark igniter. Smoke production was moderate to high, particularly in the low temperature nonflaming mode. The sample weight loss over the 550°-750°C range was 60-63 percent leaving a bulky, gray-and-white ash that retained considerable structural integrity.

A3-7X14-2

This composite, containing Neoprene and an unnamed proprietary compound, failed to ignite spontaneously at 550°C and autoignited only occasionally at 750°C. Considerable black smoke was produced, particularly in the low temperature nonflaming mode. Weight loss was 77-81 percent over the 550°-750°C range with a white porous-ash residue. Reliable ignition with the spark igniter was obtained at 550°C and that temperature was selected for the low temperature modes; the spark igniter was also used at 750°C to insure flaming combustion.

A5-00-3

Decomposition products from this large (1-in dia) armored conductor ignited spontaneously at 750°, 550°, 525°, and 500°C, requiring a temperature of 475°C to achieve the low temperature nonflaming condition. Sample weight loss over the 475°-750°C range was 65-67 percent; residue was a white, flakelike ash. The spark successfully ignited the combustion gases at 475°C for the low temperature flaming condition.

A5-14-1

This ethylene-propylene rubber/Hypalon insulation produced gases that could be ignited with the spark igniter at 550°C but did not flame spontaneously at 550°C or 750°C. Moderate smoke was noted in the low temperature nonflaming mode with decreasing amounts produced by both the high temperature and low temperature flaming modes. Sample weight loss over the 550°-750°C range was 58-62 percent; the residue was a porous, gray-and-white ash. A temperature of 550°C was selected for the low temperature modes and 750°C, with spark ignition, for the high temperature flaming mode.

A6-4X12-1

This silicone rubber/glass braid insulation autoignited occasionally at 550°C and produced very little smoke in any of the burning modes. Sample weight loss was variable (24-37 percent) and seemingly independent of temperature (31 percent at 750°C). The silicone rubber insulation swelled on heating, retained much of its structural integrity after combustion, and in the flaming modes left a fine, white, ashy deposit downstream. The glass braid appeared unaffected except for a complete loss of color. The temperature for flaming and nonflaming combustions was 550°C, with 750°C for high temperature flaming combustion.

A7-24X19-5

This multicomponent material ignited spontaneously at 550°C and 525°C, requiring a temperature of 500°C for the low temperature flaming and

nonflaming modes. Sample weight loss at 500°C was 83-85 percent, and only slightly more (86-87 percent) at 750°C. Residue was a porous black char. Moderate smoke was produced at the 750°C high temperature flaming mode, with somewhat less being produced at the lower temperature.

A2-6/2X19-4

Autoignition occurred with this polyethylene-containing composite at 750°, 550°, and 500°C, but not at 475°C. The low temperature flaming condition was achieved at 475°C using the spark igniter. This material produced very dense smoke in the high temperature flaming (750°C) mode and somewhat less smoke at the lower temperature. Sample weight loss was 97-100 percent, the residue consisting of a gray powdery ash with a small amount of black char.

TEMPERATURE PROTOCOL

The high temperature tests were conducted at 750°C for all 14 materials. Not all materials could be ignited (spark) at a single temperature that would also not lead to autoignition for at least one material in the absence of spark. Consequently it required a total of four separate temperatures for the 14 materials, in order to evaluate the flaming mode (with a spark) and the nonflaming mode at the same temperature. The temperatures that were selected for each mode and material are listed in Table 2.

TOXICITY VS. THERMAL MODE

For a given material, thermal degradation at two different temperatures may or may not yield gaseous products of differing toxicities. Furthermore, if the toxicities are different, there is no consistent observation that the most toxic condition will always be the higher or the lower temperature, or the flaming as opposed to the nonflaming mode.

A comparison of the effect of the thermal protocol on the relative toxicities of each of the 14 insulating materials, as measured by standard time-to-incapacitation, is presented in Table 3. Each of the three thermal modes was compared to the other two modes, and the determination of a statistically significant difference was made on the basis of Student's t-test. For these 14 materials, we see from Table 4 that there was a tendency for the lower temperature modes to be less toxic than the 750°C mode, but this association was not an absolute one. Furthermore it is not yet clear whether this temperature-related toxicity level is due solely to relative release rates, or to a combination of rate and composition, of gaseous products.

LOW TEMPERATURE, NONFLAMING CONDITION

This mode of thermal degradation yielded the results summarized in Table 5 for observed response times, in Table 6 for standard response times, and in Table 7 for the response times normalized to an equivalent sample weight loss of 1.0 gram (Loss t_r). The materials are listed in each table, from top to bottom, in order of increasing toxicity based on incapacitation times. The raw data collected during these tests appear in Appendix A, Table A-1.

The changes in position of materials from Tables 5 and 6 to Table 7 are reflections of the fractional part of each sample that was not thermally decomposed during its 10-minute heating regimen in the furnace. The most dramatic change in calculated t_i occurred with the two silicone rubber-containing materials (A6-4X12-1 and 1-16-1); a result, no doubt, of the fact that approximately 60-70 percent of their weights consisted of residue and consequently produced large changes in Loss-t_i values. One silicone material (1-16-1) and PVC (A1-14-1) were the only ones for which 14-day mortality was not 100 percent in this thermal mode.

LOW TEMPERATURE, FLAMING CONDITION

Mean response times are presented in Tables 8, 9, and 10. Raw data from these tests are in Appendix A, Table A-2. Materials are listed in order of decreasing response times (increasing toxicity). It should be noted that the decomposition products from Halar could not be ignited at a temperature below 750°C; therefore, the indication in tables of 750 F-- for flaming. Silicone-containing materials (1-16-1 and A6-4X12-1) once again assayed the least toxic by Obs and Std t_i, as they did under the low temperature nonflaming condition; they were also the least toxic by Loss t_i calculation. Kapton (13-16-1) was the most toxic by all calculations for this thermal mode.

HIGH TEMPERATURE, FLAMING CONDITION

Results of tests conducted under this condition (temperature of 750°C; flaming conbustion, either spontaneous or spark-induced) are presented in Tables 11, 12, and 13. The raw data are in Appendix A, Table A-3. Based on Obs and Std t_i, the two silicone-containing materials (A6-4X12-1 and 1-16-1) again assayed least toxic and Kapton (13-16-1) most toxic. When measured by Loss t_i, however, Teflon (12-20-2) rates slightly less toxic than the silicone rubber/polyolefin (1-16-1) at 750°C, while Kapton (13-16-1) remains as the most toxic.

Since the behavior of Halar (12-12-4) was atypical, the assignment of animal response data to specifically named burn mode categories was somewhat

arbitrary. During preliminary tests, we found that a minimum temperature of 750°C was required to permit reliable spark ignition and self-sustaining, flaming combustion. Since 750°C had been selected for the high temperature flaming mode for all materials, it was obvious that no true low temperature flaming mode (lower than 750°C) could exist for Halar. Therefore, both flaming and nonflaming tests were performed at 750°C and nonflaming tests were also performed at 600°C for comparison. Animal response data for each test condition were then assigned to the respective burn mode categories as follows (for Halar only): 600°C, nonflaming--LTNF; 750°C, flaming--LTF; 750°C, nonflaming--HTF.

SPECIAL COMMENTS ON TEFLON (12-20-2)

The thermal decomposition behavior of Teflon was rather unusual, especially at 750°C. The gases would momentarily ignite, quench, reignite, etc. The Std t_i's for Teflon under conditions of LTNF were significantly different ($p < 0.05$) from those obtained under HTF conditions; 6.7 minutes vs. 11.2 minutes respectively (calculated Student's t = 5.68; table t(0.975) = 2.22). If one compares these response times to the mean Std t_i (750°C) resulting from all four tests of 12 animals, Std $t_i = 8.2 \pm 4.43$, it is obvious that the mean response at 750°C is not distinguishable from either of the other two responses. However, examination of the response times for the individual tests conducted at 750°C with Teflon (see Appendix A, Table A-3) suggested the formation of two distinctly different decomposition mixtures. Two of the four tests resulted in t_i's similar to those of the LTF tests, while the remaining two tests gave results more like the LTNF results. The mean Std t_i for the first two tests is 4.8 ± 2.4; the mean Std t_i for the last two tests is 11.8 ± 2.9. These mean Std t_i's, for two replications each, are significantly different by Student's t-test ($p < 0.05$).

So it is possible that we obtained <u>partially</u> flaming decompositions, and whichever mode predominated determined that the t_i would be more like the flaming or the nonflaming response at the lower temperature. As a consequence our classification of all four 750°C Teflon tests as "flaming" ones may be a judgment influenced as much by format considerations as by reality.

RANKING OF MATERIALS BY RELATIVE TOXIC POTENTIAL

<u>Time-To-Incapacitation vs. Time-To-Death</u>

The rationale for the preference of t_i over t_d as a physiological endpoint for combustion toxicity studies is a compelling one for the following reasons: (i) It has been the general observation that many, if not most, potential victims in a developing fire situation either remove themselves from the hazardous environment or perish in it. In such situations, the onset of physical incapacitation and the corresponding loss of the ability to escape is tantamount to death. (ii) In the evaluation of animal responses to

the combustion products from hundreds of materials, a rather general observation has been the lack of any constant value for the t_d/t_i ratios among the various materials. For some atmospheres death occurs rather soon after incapacitation; for others incapacitation may occur as early as 5 minutes with all animals surviving the total 30-min exposure period (1). It is therefore obvious that if incapacitation is equivalent to nonsurvival, the relative threat posed by different materials could be significantly misrepresented if the materials were ranked according to the t_d's they produced.

Observed t_i vs. Normalized t_i

In the experimental measurement of inhalation toxicity, it is obvious that the quantity of toxic gas(es) taken into the lungs over a specified time interval is a function of the experimental subject's volumetric respiratory rate (VRR). Since it is well known that, for a given activity level, an animal's VRR is a function of its body mass (2), it follows that the magnitude of an inhalation dose acquired over a given interval of time will also be a function of its body mass.

In the case of those toxic gases that react stoichiometrically with some vital biological component(s) such as hemoglobin, cytochromes, enzymes, or any essential metabolite, one would expect to observe a quantitative relationship between the acquired dose of toxicant and the measured biological response to it. Gases such as carbon monoxide (CO) and hydrogen cyanide (HCN) are examples of toxic agents exhibiting this relationship, and our prediction is that hydrogen sulfide (H_2S) will also. We have previously shown (1) that, for CO and HCN, the effective dose required to elicit a given response is directly proportional to body mass, and the rate at which the dose is acquired by inhalation is inversely related to body mass raised to the 0.25 power--$Wt^{0.25}$; therefore, two animals having different body masses would have respective response times (to identical atmospheres of CO or HCN) such that their ratio would equal the ratio of their respective body masses raised to the 0.25 power.

$$t_r1/t_r2 = \left[\text{Body Wt, } 1/\text{Body Wt,}2\right]^{0.25}.$$

One can take advantage of this relationship, under the proper circumstances of a toxicity that is primarily due to stoichiometrically reacting gases, to correct for the inability to have all experimental animals at a single body weight on the day of an exposure. This is the normalization that we have called "Std" t_r and it signifies that the t_r's for all animals have been mathematically converted to that t_r equivalent to a body mass of 200 g.

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(2) Guyton, A. C.: Measurement of the Respiratory Volumes of Laboratory Animals, AM. J. PHYSIOL., 150:70-77, 1947.

The authors have no hesitation concerning the use of this normalization in those cases for which the major toxic components of an atmosphere are one or more of the aforementioned gases. The validity of such an approach has been strengthened in the past by the observation that the precision of replicate measurements of t_i (as measured by relative standard deviations) increases significantly when Obs t_i is converted to Std t_i.

In the present study it was difficult to determine that normalization to a body weight of 200 g represented any decided improvement in precision, for the relative standard deviations (SD/mean) for Std t_i are less than for Obs t_i in only about one-half of the cases. This could mean that for these specialized materials there was less stoichiometry between the quantity of toxic gases inhaled and the magnitude of the biological response than had been the case for materials in general, and probably reflects their increased production of irritating gases.

For the present we still favor basing our final comparative evaluations on Std values, but we are including all of the data for nontransformed measurements (Obs t_r's) so that others may evaluate this decision (see Appendix A).

An additional normalization that the authors have utilized previously, as well as in the present report, is Loss t_r. The validation for this conversion also pertains only to experiments conducted with the stoichiometrically reacting gases. We have observed that, within experimental error, doubling the concentration of one of these gases doubled the biological response of the animal; that is, $(1/t_r)$ was doubled, or the t_r was halved. We further observed that when the quantity of a polymeric material placed in the furnace was doubled, the production of CO or HCN essentially doubled. Therefore, within reasonable limits, animal response was directly proportional to sample weight in those cases for which the major toxic products were CO, HCN, and/or H_2S.

The rationale for reporting Loss t_r's in the present report was the fact that some of the samples contain components that are thermally stable. Consequently, for some materials the atmospheres to which the animals were exposed represented the decomposition products from the entire gram of material placed in the furnace, while for other materials, that were also loaded at the 1-gram level, the decomposition products were evolved from something less than 1 gram. In the specific case of the silicone rubber/polyolefin specimen (1-16-1), the test atmosphere was evolved from only 400 mg, or possibly more accurately, there was always a residue in the combustion boat that weighed approximately 600 mg.

For many readers, the Loss t_r values may be of little or no interest, but for the benefit of those who may have an interest in comparing relative toxicities for equal weights of material decomposed we have chosen to include them.

Concept of Worst Case Performance

It has been our experience, with almost 200 materials, that no single mode of thermal degradation consistently yields a more toxic product mixture than any other mode. For this reason we support, at this time, the principle that the toxic ratings by which one material should be compared to another should be the most toxic response obtained for each material, regardless of which thermal decomposition mode produced that response--that is, so long as the thermal conditions represent those to which a material could be reasonably expected to be exposed in a real fire situation.

Therefore we have identified for each material in this study the shortest t_i produced by any of the thermal modes and designated this as the "worst case" rating for that material. This process has been repeated for each of the three types of t_r's presented (Obs, Std, and Loss). These selected worst case values were then arranged in the order of decreasing t_i magnitude (increasing toxicity). The results are shown in Tables 14-16 for Obs, Std, and Loss t_i, respectively. These tables also identify that thermal mode responsible for the worst case performance.

It is obvious from the tables that results based on Obs and Std t_i's are essentially the same; only one material moved more than one place. A7-00-2 moved from third place for Obs t_i to sixth place for Std t_i. This change in rank, however, involved a change in t_i of only 0.2 min (from 7.5 to 7.3 min), an insignificant difference when one considers these measurements' having SD's of 0.6-0.7 min. The rank-order on worst case Loss t_i's, however, presents a different picture.

As stated earlier, we would normally base our evaluation at this time on the "worst case performance, Std t_i" (Table 15). This would be the case for this report also were it not for the fact that the material category of electrical insulation requires additional consideration. These considerations are discussed below.

Ranking of Electrical Insulation on the Basis of Potential Toxic Hazard per Unit Length of Conductor

It seems most logical to rank materials on the basis of those weights of each material that would be necessary to satisfy the same end-use requirement. For conductor insulation, this would be the quantity needed to cover a specified length of electrical conductor of a specified wire gauge. Therefore, the proper basis for comparison would be the weight of insulating material per unit length of equal-gauge conductor, e.g., grams of material/meter.

Once a measure of relative toxicity based on equal sample weights (e.g., Std t_i) has been accomplished, it is a simple arithmetic exercise

to convert to relative toxicity based on equal lengths. (This conversion does assume that, for a given material, toxicity is proportional to sample weight.) Response times normalized in such fashion are designed t_r'. It is these respective t_r'-values that would be utilized to compare the relative potential toxicities of alternate materials, and they would be calculated as follows:

$$t_r' = \frac{t_r \cdot a \cdot b}{100} , \qquad (1)$$

where

t_r' = calculated t_r for 1 meter of conductor, in min

t_r = response time for 1 g of insulation, in min

a = length of insulation per gram, in cm

b = number of conductors per assembly

100 = cm/meter.

In the specific case where two or more materials were to be compared (for relative toxicity of thermal degradation products), one could summarize as follows:

a. Ideally each insulation test specimen should be taken from wires of the same gauge, should be of equal weight (1 g), and should reflect the cross-sectional composition of the original system. The weight of insulation per unit length of wire should also be determined. With these data one can then compare materials on the basis of a response time calculated directly for the total weights of each material necessary to accomplish the same job.

b. If the materials under consideration have not been tested under conditions specified in (a), but have been (or can be) tested as equal-weight specimens from wires of different gauges, one may be able to calculate appropriately relative response times, under certain conditions. For example, if a material, samples from X-gauge, were to be used as a Y-gauge installation, one could calculate an appropriate Y-gauge t_r provided the insulation is either (i) homogeneous for both gauges, or (ii) heterogeneous but of constant cross-sectional composition in both the X- and Y-gauges.

c. If conditions described for (b) are not met, then valid comparisons can be made only from tests made directly on each candidate material. If these tests have not been made, or the appropriate materials are not available for conducting such tests, then those materials simply cannot be evaluated for relative toxic potential.

Examples of these conversions are discussed and illustrated in Appendix D.

For the 14 materials in this study, the t_i'-values based on worst case performance are presented in the last column in Table 17. The fact that the 14 materials are presented as six groups of two or three materials each, rather than in ranked order as a single group of 14, emphasizes the impossibility of comparing some multicomponent materials if the test specimens are from wires of different gauge, and if the value of (a) in Equation (1) is not available. Unfortunately such was the case for many of the specimens submitted for testing in this study.

Relative rank-order has been indicated for those materials submitted on wires of the same gauge. Rank was based on the relative magnitude of t_i' (last column), which represents the predicted time-to-incapacitation (in minutes) for a 200-g rat if the weight of insulation from 1 meter of wire were to be thermally decomposed under the conditions in column 3 (Thermal Mode). Note that the table values of t_i' have all been multiplied by 100 for tabular convenience. Therefore, the t_i that one would predict from the quantity of Tefzel (3-20-1) found on 1 meter of 20AWG wire would be 2.60 min (x 100 = 260).

For the 20AWG wires, on an end-use basis, Tefzel would seem to be the least toxic choice of the three, and Exane (11-20-1) would be the most toxic.

We see, in the third group, an appropriate demonstration of the fact that comparisons must be made on the proper basis. Throughout a majority of all the tests performed on Kapton (13-16-1) and Silicone/PO (1-16-1), and continuing for most of the normalizations that were made, the Silicone/PO material was most often the least toxic and Kapton the most toxic of all the materials--when equal weights of sample were tested. However, when the burden of "worst case performance" is imposed, and when one compares total weights of material per job, Kapton would seem to present only half the toxic threat that Silicone/PO would--when both are used the same way.

A rank-ordering of all 14 materials, in terms of their potential relative toxicities, can be achieved from the results of this study, but only on the basis of comparing equal weights of material. Table 15 depicts relative rank-order on the basis of equal sample weights placed in the furnace. The Std t_i's listed in column 5 do reflect the worst case potential toxicities for the materials themselves, and would represent the starting points for calculating end-use relative hazards provided one knew the relative total weights of the various materials required to accomplish that end-use.

With emphasis on the restriction that we are talking only about "equal-sample-weight relative toxicities," some comments concerning the results in Table 15 can be made.

a. The first six, least toxic materials are from the group of materials in current use, i.e., present generation materials. Of the five "best state-of-the-art," or next-generation materials, three were found to be the three most toxic, and four of the five were among the six most toxic materials.

b. The two silicone-containing materials were ranked in adjacent positions, Nos. 1 and 2, the least toxic ranks.

c. The two PVC-containing materials were ranked in adjacent positions, Nos. 3 and 4.

d. The three polyethylene-containing materials ranked as Nos. 3, 5, and 8, with a 0.6-min spread among their values.

e. The neoprene-containing material (A7-00-2), in rank 6, appears significantly different from (A3-7X14-2), rank 11. The presence of a "proprietary compound" in the latter seems to have resulted in increased toxicity.

f. The presence of sulfur in the EPR/Hypalon may have resulted in increased toxicity over the Neoprene (ranks 10 and 6 respectively), but not so much an increase as the "proprietary compound" produced (rank 11). The relative proportion of EPR to Hypalon, however, was not known.

g. The two fluorine-containing, new-generation materials, Halar and Tefzel, were surprisingly more toxic than Teflon, ranks 12 and 13 vs. 9, respectively.

h. The most toxic rank fell to Kapton, rank 14. This is most likely a result of the nitrogen content (of this polyimide material) and its potential for conversion to volatile cyanides.

For results based on a loss of equal weights of sample, which would be a measure of the relative toxicity of the gases actually produced, we look at Table 16.

a. The two silicones are still ranked least toxic, despite the 10- to 15-minute decrease in their normalized values for t_i.

b. Teflon exhibits the most dramatic shift in relative rank of all the materials. It now occupies the third least toxic rank, immediately following the silicones, a move of six places from the rank 9 position of Table 15.

c. Neoprene (A7-00-2) changed rank by 5 positions to a more toxic location than before, and (A5-00-3) went from rank 5 to rank 9.

d. The polyethylene/PVC/grease (A7-24X19-5), the all-polyethylene (A2-6/2X19-4), the Hypalon (A5-14-1), and the (A3-7X14-2) materials all changed rank by only two positions, two materials moved up and two materials moved down.

e. The three materials ranked most toxic in Table 15 (ranks 12, 13, and 14) now occupy ranks 10, 12, and 14 respectively.

f. Kapton is again in the most toxic position.

One additional observation from Tables 15 and 16 is of interest. The thermal mode that yielded the most toxic products was the high temperature flaming (HTF) mode for 10 of the 14 materials; for the remaining 4, the most toxic mode was nonflaming. If all 14 materials had generated their most toxic products under flaming conditions, one might have reasonably concluded that this was because the decomposition proceeded at a faster rate in the flaming mode, and consequently the toxic atmosphere was generated earlier than in the nonflaming mode. The observation that four materials did not behave in this fashion suggests that a reasonable explanation should be pursued in later research.

CAUTIONS AND LIMITATIONS

It is obvious that the discipline of combustion toxicology is yet an immature one, struggling even to establish itself as a descriptive science. And yet, because of the need for solutions to potentially serious problems that face society--and technology--today, this neonatal area of research is being pressed for performance--answers, predictions, correlations, etc--that is at, or maybe beyond, the very limits of its capabilities.

The data reported herein were derived by a protocol that basically has been used for several years to evaluate approximately 200 polymer materials and several discrete gases. The authors have little concern over the repeatability of the reported results, nor for the interpretations based on them, so far as their application to this one system is concerned. However, performance in this small-scale laboratory system is not per se one of the aforementioned serious problems facing society. There is, at the present time, little scientifically demonstrated evidence that the toxic behavior of real materials involved in real fires can be successfully predicted by any laboratory-scale model. There is even more disagreement than agreement, as to the relative toxic potential of materials, among the results of the various laboratories utilizing small-scale protocols.

Some laboratories have adopted protocols that are significantly different from the CAMI approach for obtaining such relative values (3,4,5,6,7), and despite a methodological precision in the reproduction of results that for some may approach that of the CAMI method, the relative toxicities assigned to the same materials by these various procedures may differ significantly, or even dramatically.

As an example, a very recent paper by Anderson and Alarie (3) reported the relative evaluation of 17 polymeric materials. They utilized two separate protocols and reported that polytetrafluorethylene (PTFE) was the most toxic of the 17 materials, was "more than 100 times more toxic than Douglas Fir," and belonged in the category of "Super Toxic" materials. The CAMI protocol results ranked Teflon, 12-20-2 (PTFE) ninth of the 14 materials tested, with 5 materials being more toxic than Teflon (Table 15). Previous evaluations of Douglas Fir by the CAMI protocol found it to have a Std t_i of 5.3 min, a t_i that would place it 12th in Table 15. Compared to the Std t_i of 6.7 min found for Teflon, the CAMI protocol therefore would evaluate Teflon as being measurably less toxic than Douglas Fir, rather than over 100 times more toxic.

Hilado et al. (4) compared results from the USF*/NASA methodologies with those obtained from the FAA/CAMI protocol for the same materials; in none of

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(3) Anderson, R. C. and Y. C. Alarie: Screening Procedure to Recognize "Supertoxic" Decomposition Products from Polymeric Materials under Thermal Stress, J. COMB. TOX. 5:54-63, 1978.

(4) Hilado, C. J., H. J. Cumming, A. M. Machado, J. E. Schneider, C. R. Crane, D. C. Sanders, B. R. Endecott, and J. K. Abbott: Comparison of Animal Responses to the Combustion Products Generated by Two Test Procedures, the USF/NASA Methodology and the FAA/CAMI System, J. COMB. TOX., 4:325-359, 1977.

(5) Kimmerle, G.: Aspects and Methodology for the Evaluation of Toxicological Parameters During Fire Response, J. FIRE FLAM/COMB. TOX., 1:4, 1974.

(6) Birky, M. M., I. N. Einhorn, N. L. Grunnett, S. C. Packham, J. H. Petajon, and J. D. Seader: Physiological and Toxicological Effects of the Products of Thermal Decomposition from Polymeric Materials, NBS SPECIAL PUBLICATION 411:105-124, November 1974.

(7) Potts, W. J. and T. S. Lederer: A Method for Comparative Testing of Smoke Toxicity, J. COMB. TOX. 4:114-162, 1977.

* University of San Francisco

seven separate temperature-profile variations of the USF/NASA method were the four test materials ranked in the same order as they were by the FAA/CAMI system. More significantly, all seven USF procedures consistently ranked an ABS polymer most toxic while the CAMI method ranked it next-to-the-least toxic.

Many such examples could be cited, and the inescapable conclusion is that one must combine caution with common sense in any attempt to relate such laboratory exercises to any frame of reference other than that one from which the data originated.

The authors must therefore emphasize that the results reported in this study, and the interpretations based on those results, may not be directly applicable to thermal situations other than those utilized in the generation of the data. It is especially important to realize that the relative merit assigned to materials as a result of these tests could be entirely different from their relative merit based on behavior in a full-scale, uncontrolled fire.

SUGGESTIONS FOR FUTURE RESEARCH

a. The possibility that one distinct mode of thermal degradation could always result in generation of the most toxic atmosphere should be investigated further. If this proves untrue, then an attempt should be made to define the least number of test conditions that would have to be utilized in testing any material to insure that the "worst case" condition has been included.

b. The validity of converting animal response times from those measured for a defined sample weight to those expected for some other weight of material should be verified for gas mixtures that contain significant quantities of the irritant toxic gases. The present validation for such conversions was established only for the stoichiometrially reacting gases. Without that capability, materials could never be ranked for full-scale use from the results of small-scale tests. In addition, each set of materials would have to be tested with sample weights in the same quantities as were to be used in the installation.

c. Ultimately the attempts have to be made to: identify those gases in combustion products that are responsible for the toxicity of the mixture; determine the individual contribution of each to the total toxicity; and devise a means for realistically assessing the toxicity of gas mixtures from chemical analyses rather than by animal exposures.

d. The ability of any small-scale test system to predict the consequences of a full-scale fire is the final authority for acceptability of a method. Eventually such correlations must be evaluated.

SUMMARY

The CAMI procedure for evaluating the relative toxicities of combustion products, using a combustion tube in a closed system with the subjects contained in rotating cages, proved suitable for the modifications required for testing electrical conductor insulation at different degradation temperatures, under both flaming and nonflaming oxidative conditions.

For each of the 14 subject materials, exploratory tests identified a temperature at which both nonflaming and flaming thermal degradations could be achieved; ignition to produce flaming combustion was accomplished with an electric spark. This temperature was not the same for all materials.

For each of the three different thermal degradation conditions, the relative potential toxicity of the decomposition products from an equal weight of each material was assigned a rank-order (from least toxic to most toxic potential), based on the relative values of the observed times-to-incapacitation (t_I). A rank-order was also established for each of the two normalized values for t_I, i.e., Std t_I and Loss t_I.

The concept of a "worst case performance" was presented as a possible standard basis for rating relative toxic hazards of materials, and a rank-order based on this concept was derived for the materials tested.

Based on the "worst case" results from equal 1.000-g quantities placed in the furnace (toxic potential for the material), the relative rank-order of the 14 materials was as follows, in order of increasing toxicity:

(A6-4X12-1, a silicone) < (1-16-1, a silicone) <
(A7-24X19-5, polyethylene/PVC) < (A1-14-1, PVC) <
(A5-00-3, polyethylene foam) < (A7-00-2, Neoprene) <
(11-20-1, Exane) < (A2-6/2X19-4, polyethylene) <
(12-20-2, Teflon) < (A5-14-1, Hypalon) <
(A3-7X14-2, Neoprene/proprietary component) <
(12-12-4, Halar) < (3-20-1, Tefzel) < (13-16-1, Kapton).

An additional rank-ordering based on the relative potential toxicity of each that would occur if a given length of one material were replaced by another in a specific, defined application could not be achieved for all 14 materials because the sample specimens were not all available in equal-gauge sizes. A relative ranking was presented, however, for each group of materials that was supplied on wires of equal gauge (Table 17) as an example of the possible application of test results to applied, end-use problems.

A discussion was presented as an appendix that suggests techniques by which the measured toxicity of an insulation from wire of one size could be converted to equivalent toxicities for that same insulation on wires of other sizes--provided information concerning the weight of insulation per unit length of wire is available.

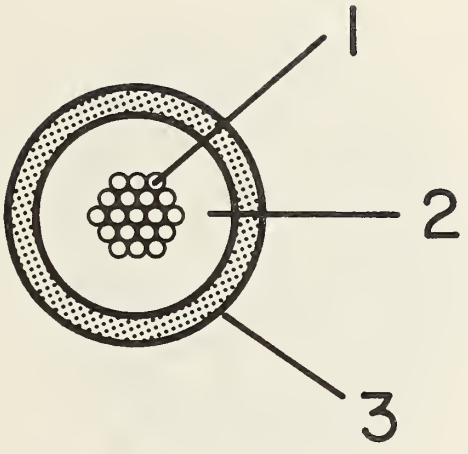

FIGURE 1. CROSS-SECTION, SAMPLE NO. 1-16-1
Silicone rubber/cross-linked, modified polyolefin
Outside diameter 4 mm.

1. Single-strand, tinned copper conductors.
2. Silicone rubber insulation.
3. Polyolefin outer jacket.

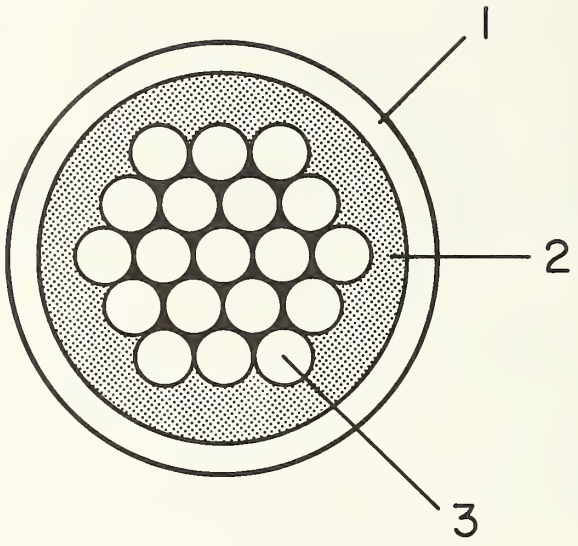

FIGURE 2. CROSS-SECTION, SAMPLE NO. A7-00-2
Ethylene-propylene rubber/Neoprene jacket.
(EPR and Neoprene layers are bonded together.)
Outside diameter 16 mm.

1. Neoprene jacket.
2. Ethylene-propylene rubber.
3. Copper conductors.

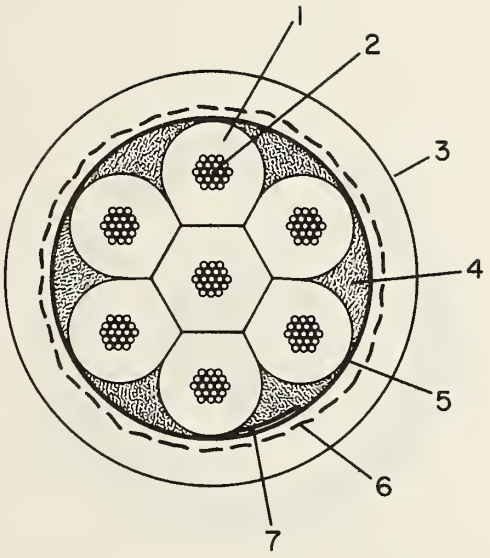

FIGURE 3. CROSS-SECTION, SAMPLE NO. A3-7X14-2
Proprietary compound/cloth tape, Neoprene jacket.
Outside diameter 25 mm.

1. Individual wire bundle insulation.
2. Wire bundle, stranded copper.
3. Outer (Neoprene) jacket.
4. Fiber.
5. Cloth, cemented to outer jacket.
6. Cloth mesh embedded in outer jacket.
7. Fiber tape, approximately 4 mm wide, running longitudinally along the cable.

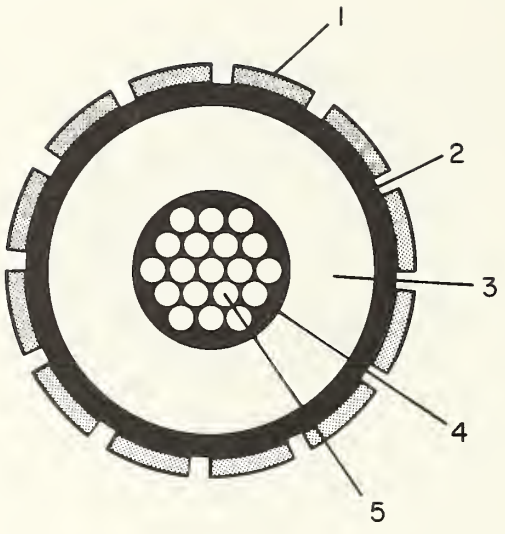

FIGURE 4. CROSS-SECTION, SAMPLE NO. A5-00-3
XL Polyethylene/Semi-Conductive Jacket/
14 (3/16 x .027) tinned Cu armor
over jacket. Outside diameter 25 mm.

1. Metal armour consisting of spirally wound, flat, tin-plated, copper strips not bonded to insulation.
2. Black outer jacket.
3. Pink foam insulation layer.
4. Black inner insulation layer.
5. Single-strand copper conductors.

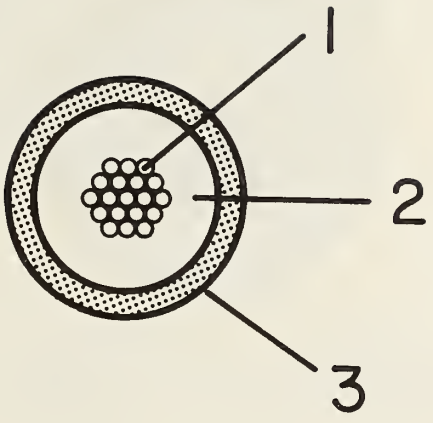

FIGURE 5. CROSS-SECTION, SAMPLE NO. A5-14-1
Ethylene-propylene rubber/Hypalon jacket.
Outside diameter 6 mm.

1. **Single-strand conductors.**
2. **Ethylene-propylene rubber insulation.**
3. **Hypalon jacket.**

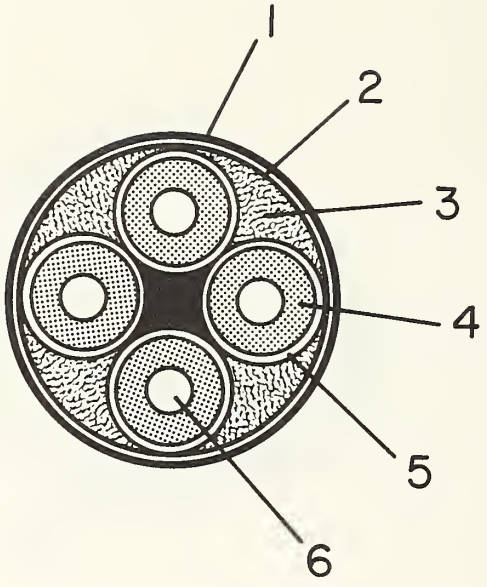

FIGURE 6. CROSS-SECTION, SAMPLE NO. A6-4X12-1
Silicone rubber-glass braid/Mylar tape/glass braid. Outside diameter 12 mm.

1. Black glass braid jacket.
2. Clear Mylar tape.
3. Fiber filler.
4. Gray silicone rubber individual wire insulation.
5. Color-coded glass braid jacket.
6. Conductor.

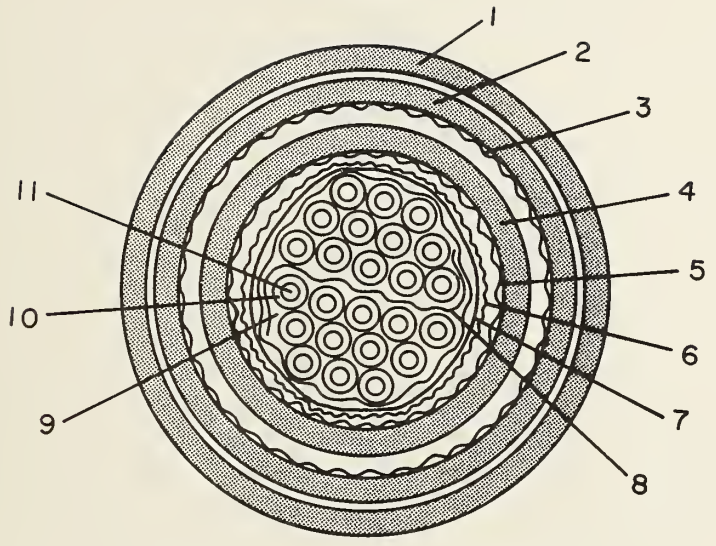

FIGURE 7. CROSS-SECTION, SAMPLE NO. A7-24X19-5
Polyethylene/Film-shield/Aluminum shield/
Polyethylene/Aluminum shield/Polyethylene/PVC-
Grease impregnated. Outside diameter 30 mm.

1. Black outer jacket.
2. Black inner jacket, not bonded to (1).
3. Corrugated aluminum bonded with adhesive to (2).
4. Black insulation layer not bonded to (3), but bonded to (5) with adhesive.
5. Second corrugated aluminum layer.
6. Clear plastic strip, 2 in wide, spirally wrapped around (7) and (8).
7. White translucent twisted fiber spirally wrapped around (8).
8. "S"-shaped (cross-section) sheath composed of aluminum foil laminated between two layers of flexible clear plastic and dividing the conductors into two 12-wire bundles.
9. Yellow grease filling the internal space between the individual insulated conductors and saturating all layers but to the inner surface of (3).
10. Color-coded individual conductor insulation.
11. Single-strand copper conductor.

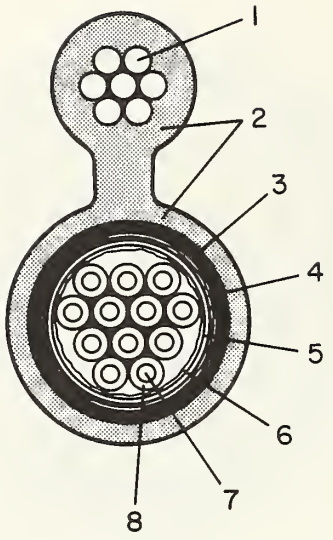

FIGURE 8. CROSS-SECTION, SAMPLE NO. A2-6/2X19-4
Polyethylene/Copper shild/Film/polyethylene, with 7-strand steel messenger (shaped in the form of a figure "8"). Outside diameter of conductor section 15 mm, messenger section 9 mm.

1. **Steel wire.**
2. **Black polyethylene outer jacket.**
3. **Copper shield.**
4. **Spirally wrapped string.**
5. **Clear plastic film.**
6. **String wrapped spirally around wire bundle.**
7. **Copper conductor.**
8. **Individual conductor insulation.**

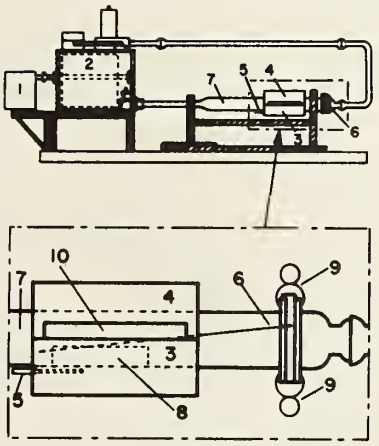

FIGURE 9. COMBUSTION/EXPOSURE ASSEMBLY

1. Gearmotor, model 3M126, 6 rpm, 1/20 hp, Dayton Manufacturing Company, Chicago, Illinois.
2. Animal Exposure Chamber.
3. Heating Unit, model NV2X6, 425 W at 57.5 V, semi-cylindrical, Aten, Ltd. (Now Watlow Electric Manufacturing Co., 12001 Lackland Road, St. Louis, Missouri).
4. Same as item 3. (The insulation unit, with an observation slot cut into the side as shown, was replaced with a second heating unit for this series of tests.)
5. Thermocouple, chromel-alumel, Omega Engineering Inc., Stamford, Connecticut.
6. Spark Igniter.
7. Combustion Tube.
8. Combustion Boat.
9. Spring Clamp.
10. Observation Slot (see item 4).

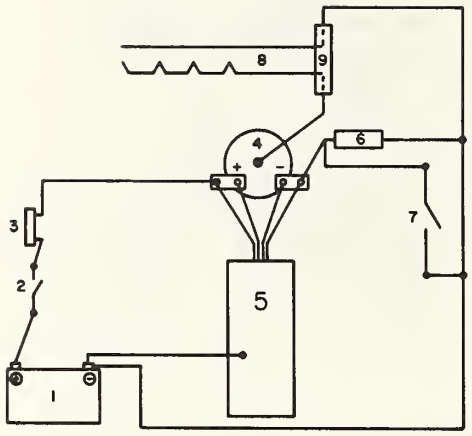

FIGURE 10. SPARK IGNITER ASSEMBLY

1. Battery, 12 VDC.
2. On-off switch.
3. Ballast resistor.
4. 12 V automotive ignition coil.
5. Capacitive discharge ignition unit.
6. Condenser.
7. Motor-driven switch (750 contacts/min).
8. Igniter.
9. Electrode holder.

TABLE 1. PHYSICAL DESCRIPTION OF CONDUCTOR AND INSULATION

Material No.	Linear Density Wire & Insuln., g/cm	Composition		Length/Unit Wt Insuln. Only, cm/g
		Wire Only, Wt %	Insuln. Only, Wt %	
11-20-1 (Exane)	0.1225	45.2	54.8	14.89
12-12-4 (Halar)	0.3544	76.8	23.2	12.16
13-16-1 (Kapton)	0.1357	87.9	12.1	60.90
1-16-1 (Silicone/PO)	0.2453	46.5	53.5	7.62
12-20-2 (Teflon)	0.0906	61.1	38.9	28.37
3-20-1 (Tefzel)	0.0706	75.2	24.8	57.11
A1-14-1 (PVC)	0.2120	80.2	19.8	23.88
A7-00-2	7.8615	78.5	21.5	0.59
A3-7X14-2	7.8937	17.3	82.7	0.15
A5-00-3*	12.9362	45.7	30.0	0.26
A5-14-1	0.5432	67.7	32.3	5.70
A6-4X12-1	2.4086	49.9	50.1	0.83
A7-24X19-5†	9.7525	13.7	68.0	0.15
A2-6/2X19-4	4.4488	67.1	32.9	0.68

*Metal armor, 24.3% by weight

†Aluminum shield, 18.3% by weight

TABLE 1A. TEST SPECIMEN CONFIGURATION*

Sample No.	Number of Conductors	AWG	Insulating Material(s)	Remarks
11-20-1	1	20	Exane (cross-linked polyolefin)	19 strand/32AWG tinned copper conductor
12-12-4	1	12	Halar	19 strand tinned copper conductor
13-16-1	1	16	Kapton, with polyimide finish coat	tinned copper conductor
1-16-1	1	16	Silicone rubber with cross-linked modified polyolefin jacket	tinned copper conductor (Figure 1)
12-20-2	1	20	TFE Teflon	19 strand, 32AWG silverplated copper conductor
3-20-1	1	20	Tefzel, with polyimide top coat	19 strand, 0.203 mm tinned copper conductor
A1-14-1	1	14	Irradiated polyvinyl chloride	--
A7-00-2	1	2/0	Ethylene propylene rubber/Neoprene jacket	600V, Figure 2
A3-7X14-2	7	14	Proprietary compound/ cloth tape/Neoprene	Figure 3
A5-00-3	1	2/0	Cross-linked poly-ethylene/semi-conductive jacket/ 14(3/16 in x 0.027 in) tinned copper armor over jacket, 14 pcs.	Figure 4
A5-14-1	1	14	Ethylene propylene rubber/Hypalon jacket	Figure 5

*See footnote at end of table, p. 37.

TABLE 1A. TEST SPECIMEN CONFIGURATION*--Continued

Sample No.	Number of Conductors	AWG	Insulating Material(s)	Remarks
A6-4X12-1	4	12	Silicone rubber-glass braid/Mylar tape/glass braid	Figure 6
A7-24X19-5	24	19	Polyethylene/film shield/aluminum shield/ polyethylene/aluminum shield/polyethylene/ polyvinyl chloride-grease impregnated	Figure 7
A2-6/2X19-4	12	19	Polyethylene/copper shield/film/polyethylene, 7-strand steel messenger (shaped in form of a figure "8")	Figure 8

*The specimen descriptions in this table are reprinted from Volume I, Electrical Insulation Fire Characteristics, and were supplied by the Boeing Commercial Airplane Company, Seattle, Washington.

TABLE 2. TEMPERATURES SELECTED FOR THERMAL DEGRADATION

Material No.	Temperatures, °C		
	Nonflaming	Flaming	High
11-20-1 (Exane)	550	550	750
12-12-4 (Halar)	600	750	750
13-16-1 (Kapton)	650	650	750
1-16-1 (Silicone/PO)	550	550	750
12-20-2 (Teflon)	650	650	750
3-20-1 (Tefzel)	550	550	750
A1-14-1 (PVC)	550	550	750
A7-00-2	550	550	750
A3-7X14-2	550	550	750
A5-00-3	475	475	750
A5-14-1	550	550	750
A6-4X12-1	550	550	750
A7-24X19-5	500	500	750
A2-6/2X19-4	475	475	750

TABLE 3. ANIMAL RESPONSE DIFFERENCES TO THREE HEATING REGIMENS

Material No.	Heating Regimens		Std t_i's (mean)		t-test (a vs. b) Result, (t (0.975))*
	a	b	a	b	
11-20-1	LTNF†	LTF	13.6	9.8	+
(Exane)	LTNF	HTF	13.6	7.0	+
	LTF	HTF	9.8	7.0	+
12-12-4	LTNF	750 NF	5.9	4.7	+
(Halar)	LTNF	750 F	5.9	8.1	+
	750 NF	750 F	4.7	8.1	+
13-16-1	LTNF	LTF	7.1	7.7	-
(Kapton)	LTNF	HTF	7.1	4.5	+
	LTF	HTF	7.7	4.5	+
1-16-1	LTNF	LTF	18.6	>30	+
(Silicone	LTNF	HTF	18.6	17.9	-
Rubber/PO)	LTF	HTF	>30	17.9	+
12-20-2	LTNF	LTF	6.8	11.2	+
(Teflon)	LTNF	HTF	6.8	8.3	-
	LTF	HTF	11.2	8.3	-
3-20-1	LTNF	LTF	10.4	10.3	-
(Tefzel)	LTNF	HTF	10.4	4.5	+
	LTF	HTF	10.3	4.5	+
A7-00-2	LTNF	LTF	9.5	9.1	-
	LTNF	HTF	9.5	7.3	+
	LTF	HTF	9.1	7.3	+
A3-7X14-2	LTNF	LTF	11.2	8.8	+
	LTNF	HTF	11.2	6.0	+
	LTF	HTF	8.8	6.0	+
A5-00-3	LTNF	LTF	13.4	15.2	+
	LTNF	HTF	13.4	7.4	+
	LTF	HTF	15.2	7.4	+
A5-14-1	LTNF	LTF	14.0	12.7	+
	LTNF	HTF	14.0	6.6	+
	LTF	HTF	12.7	6.6	+

*†
See footnotes at end of Table 3, p. 40.

TABLE 3. ANIMAL RESPONSE DIFFERENCES TO THREE HEATING REGIMENS--Continued

Material No.	Heating Regimens		Std t_i's (mean)		t-test (a vs. b) Result, (t (0.975))*
	a	b	a	b	
A6-4X12-1	LTNF†	LTF	22.0‡	>30	+
	LTNF	HTF	22.0‡	>30	+
	LTF	HTF	>30	>30	-
A7-24X19-5	LTNF	LTF	8.4	11.7	+
	LTNF	HTF	8.4	7.5	+
	LTF	HTF	11.7	7.5	+
A2-6/2X19-4	LTNF	LTF	6.9	10.4	+
	LTNF	HTF	6.9	7.4	+
	LTF	HTF	10.4	7.4	+
A1-14-1 (PVC)	LTNF	LTF	21.5	11.5	+
	LTNF	HTF	21.5	7.4	+
	LTF	HTF	11.5	7.4	+

*(+) = different (t (.975)); (-) = no difference (t (.975)). For a description of the t-test, see any basic statistical text (e.g., Snedecor, G. W. and Cochran, W. G.: Statistical Methods, 6th Ed., 1967, Iowa State Univ. Press, Ames, Iowa, pp. 59-60).

†LTNF = low temperature nonflaming; LTF = low temperature flaming; HTF = high temperature flaming; 750 NF = 750°C, nonflaming; 750 F = 750°C, flaming.

‡N = 8; only 8 animals were incapacitated in 30 min.

TABLE 4. LEAST AND MOST TOXIC THERMAL CONDITIONS

Material No.	Resultant Toxicity	
	Least Toxic	Most Toxic
11-20-1 (Exane)	LTNF†	HTF
12-12-4 (Halar)	750 F	750 NF
13-16-1 (Kapton)	LTF	HTF
1-16-1 (Silicone/PO)	LTF	HTF
12-20-2 (Teflon)	LTF	LTNF
3-20-1 (Tefzel)	LTF	HTF
A1-14-1 (PVC)	LTNF	HTF
A7-00-2	LTNF	HTF
A3-7X14-2	LTNF	HTF
A5-00-3	LTF	HTF
A5-14-1	LTNF	HTF
A6-4X12-1	HTF, LTF (>30)	LTNF
A7-24X19-5	LTF	HTF
A2-6/2X19-4	LTF	LTNF

* As determined by both Obs and Std t_i's. Ranking is based on mean response times only, and differences between near neighbors may not be statistically significant.

† LTNF = low temperature nonflaming; HTF = high temperature flaming; LTF = low temperature flaming; 750 F = 750°C, flaming; 750 NF = 750°C, nonflaming.

TABLE 5. OBSERVED RESPONSE TIMES, LOW TEMPERATURE, NONFLAMING CONDITION

Material No.	N*	Mean Obs t_i, Min	SD†	Mean§ Obs t_d, Min	SD†	Mortality 30-Min	Mortality 14-Day
A6-4X12-1	9	21.9‡	5.36	>30	--	5/9	9/9
A1-14-1 (PVC)	9	21.2	1.88	--	--	1/9	3/9
1-16-1 (Silicone/PO)	9	19.3	1.32	--	--	1/9	4/9
11-20-1 (Exane)	9	13.8	1.50	24.4	4.24	6/9	9/9
A5-14-1	9	13.5	1.46	19.4	2.54	9/9	9/9
A5-00-3	9	13.2	1.09	19.4	2.07	8/9	9/9
3-20-1 (Tefzel)	9	10.8	0.82	13.8	1.60	9/9	9/9
A3-7X14-2	9	10.8	1.28	15.7	2.74	9/9	9/9
A7-00-2	9	9.2	0.55	13.0	1.35	9/9	9/9
A7-24X19-5	9	8.2	0.44	11.2	1.05	9/9	9/9
13-16-1 (Kapton)	9	7.0	0.72	8.6	0.80	9/9	9/9
A2-6/2X19-4	9	6.8	0.36	9.3	0.86	9/9	9/9
12-20-2 (Teflon)	9	6.7	1.70	>30	--	5/9	9/9
12-12-4 (Halar)	9	5.8	0.26	7.7	0.58	9/9	9/9

*N = Number of experimental animals exposed.

†SD = Standard deviation.

‡N = 8; one animal did not incapacitate in 30 min.

§Mean values were calculated only for those animals with response times $\leq$ 30 min, and then only if responses were obtained for >65 percent of the exposed population.

TABLE 6. STANDARD RESPONSE TIMES, LOW TEMPERATURE, NONFLAMING CONDITION

Material No.	N*	Mean Std t_i, Min	SD†	Mean§ Std t_d, Min	SD†	Mortality 30-Min	Mortality 14-Day
A6-4X12-1	9	22.0‡	4.84	>30	--	5/9	9/9
A1-14-1 (PVC)	9	21.5	2.33	--	--	1/9	3/9
1-16-1 (Silicone/PO)	9	18.6	0.94	--	--	1/9	4/9
11-20-1 (Exane)	9	13.6	1.38	24.3	4.31	6/9	9/9
A5-14-1	9	14.0	1.28	20.4	3.00	9/9	9/9
A5-00-3	9	13.4	1.16	19.7	2.07	8/9	9/9
A3-7X14-2	9	11.2	1.25	16.3	2.95	9/9	9/9
3-20-1 (Tefzel)	9	10.4	0.82	13.3	1.56	9/9	9/9
A7-00-2	9	9.5	0.58	13.5	1.33	9/9	9/9
A7-24X19-5	9	8.4	0.42	11.6	1.12	9/9	9/9
13-16-1 (Kapton)	9	7.1	0.90	8.8	1.04	9/9	9/9
A2-6/2X19-4	9	6.9	0.28	9.4	0.89	9/9	9/9
12-20-2 (Teflon)	9	6.7	1.70	>30	--	5/9	9/9
12-12-4 (Halar)	9	5.9	0.57	7.9	0.92	9/9	9/9

*N = Number of experimental animals exposed.

†SD = Standard deviation.

‡N = 8; one animal did not incapacitate in 30 minutes.

§Mean values were calculated only for those animals with response times $\leq$30 min, and then only if responses were obtained for >65 percent of the exposed population.

TABLE 7. LOSS RESPONSE TIMES, LOW TEMPERATURE, NONFLAMING CONDITION

Material No.	N*	Mean Loss t_i, Min	SD†	Mean§ Loss t_d, Min	SD†	Mortality 30-Min	Mortality 14-Day
A1-14-1 (PVC)	9	19.1	2.09	--	--	1/9	3/9
11-20-1 (Exane)	9	11.1	1.04	19.9	3.53	6/9	9/9
3-20-1 (Tefzel)	9	9.2	0.40	11.9	1.03	9/9	9/9
A5-00-3	9	8.8	0.74	12.9	1.32	8/9	9/9
A3-7X14-2	9	8.7	0.99	12.7	2.31	9/9	9/9
A5-14-1	9	8.3	0.83	12.1	1.62	9/9	9/9
1-16-1 (Silicone/PO)	9	7.4	0.34	--	--	1/9	4/9
A6-4X12-1	9	7.3‡	1.28	>30	--	5/9	9/9
A7-24X19-5	9	7.0	0.38	9.6	0.92	9/9	9/9
12-20-2 (Teflon)	9	6.7	1.70	>30	--	5/9	9/9
A2-6/2X19-4	9	6.7	0.28	9.2	0.88	9/9	9/9
12-12-4 (Halar)	9	5.9	0.57	7.9	0.92	9/9	9/9
A7-00-2	9	5.7	0.35	8.1	0.80	9/9	9/9
13-16-1 (Kapton)	9	4.6	0.65	5.7	0.75	9/9	9/9

*N = Number of experimental animals exposed.

†SD = Standard deviation.

‡N = 8; one animal did not incapacitate in 30 min.

§Mean values were calculated only for those animals with response times ≤30 min, and then only if responses were obtained for >65 percent of the exposed population.

TABLE 8. OBSERVED RESPONSE TIMES, LOW TEMPERATURE, FLAMING CONDITION

Material No.	N*	Mean‡ Obs t_i, Min	SD†	Mean‡ Obs t_d, Min	SD†	Mortality 30-Min	Mortality 14-Day
1-16-1 (Silicone/PO)	6	--	--	S∫	--	0/6	0/6
A6-4X12-1	9	--	--	S	--	0/9	0/9
A5-00-3	9	15.7	2.22	--	--	3/9	6/9
A5-14-1	9	13.2	0.90	23.7	3.64	7/9	7/9
A7-24X19-5	9	12.1	0.90	20.9	3.57	8/9	8/9
A1-14-1 (PVC)	9	12.0	0.94	19.8	4.05	6/9	9/9
12-20-2 (Teflon)	12	11.2	2.01	>30	--	3/12	9/12
A2-6/2X19-4	9	10.6	1.17	17.5	1.96	9/9	9/9
3-20-1 (Tefzel)	9	10.4	0.60	13.1	0.98	9/9	9/9
11-20-1 (Exane)	9	9.7	0.89	23.0	7.32	7/9	9/9
A7-00-2	9	9.4	0.71	17.6	5.08	8/9	9/9
A3-7X14-2	9	9.0	0.85	13.8	1.63	9/9	9/9
12-12-4 (Halar)§	9	7.9	1.00	12.7	1.62	9/9	9/9
13-16-1 (Kapton)	9	7.7	0.26	10.1	0.55	9/9	9/9

*N = Number of experimental animals exposed.

†SD = Standard deviation.

‡Mean values were calculated only for those animals with response times $\leq$ 30 min, and then only if responses were obtained for >65 percent of the exposed population.

§Observed response times are for the 750F condition.

∫S = 14-day survival.

TABLE 9. STANDARD RESPONSE TIMES, LOW TEMPERATURE, FLAMING CONDITION

Material	N*	Mean‡ Std t_i, Min	SD†	Mean‡ Std t_d, Min	SD†	Mortality 30-Min	Mortality 14-Day
1-16-1 (Silicone/PO)	6	--	--	S∫	--	0/6	0/6
A6-4X12-1	9	--	--	S	--	0/9	0/9
A5-00-3	9	15.2	1.91	--	--	3/9	6/9
A5-14-1	9	12.7	0.84	22.5	2.43	7/9	7/9
A7-24X19-5	9	11.7	1.21	20.2	3.75	8/9	8/9
A1-14-1 (PVC)	9	11.5	0.85	18.9	3.92	6/9	9/9
12-20-2 (Teflon)	12	11.2	1.97	>30	--	3/12	9/12
A2-6/2X19-4	9	10.4	1.11	17.2	1.99	9/9	9/9
3-20-1 (Tefzel)	9	10.3	0.64	13.0	1.11	9/9	9/9
11-20-1 (Exane)	9	9.8	1.01	23.2	7.30	7/9	9/9
A7-00-2	9	9.1	0.73	16.9	4.95	8/9	9/9
A3-7X14-2	9	8.8	1.04	13.4	1.98	9/9	9/9
12-12-4 (Halar)§	9	8.1	0.99	13.1	1.62	9/9	9/9
13-16-1 (Kapton)	9	7.7	0.38	10.1	0.78	9/9	9/9

*N = Number of experimental animals exposed.

†SD = Standard deviation.

‡Mean values were calculated only for those animals with response times $\leq$ 30 min, and then only if responses were obtained for >65 percent of the exposed population.

§Observed response times are for the 750F condition.

∫S = 14-day survival.

TABLE 10. LOSS RESPONSE TIMES, LOW TEMPERATURE, FLAMING CONDITION

Material No.	N*	Mean‡ Loss t_i, Min	SD†	Mean‡ Loss t_d, Min	SD†	Mortality 30-Min	Mortality 14-Day
1-16-1 (Silicone/PO)	6	--	--	S∫	--	0/6	0/6
A6-4X12-1	9	--	--	S	--	0/9	0/9
12-20-2 (Teflon)	12	11.2	1.97	>30	--	3/12	9/12
A1-14-1 (PVC)	9	10.3	0.79	16.9	3.57	6/9	9/9
A2-6/2X19-4	9	10.3	1.11	16.9	1.98	9/9	9/9
A5-00-3	9	10.0	1.27	--	--	3/9	6/9
A7-24X19-5	9	9.9	1.07	17.0	3.18	8/9	8/9
3-20-1 (Tefzel)	9	9.6	0.51	11.3	1.86	9/9	9/9
12-12-4 (Halar)§	9	8.1	0.99	13.1	1.62	9/9	9/9
11-20-1 (Exane)	9	7.9	0.74	18.7	5.75	7/9	9/9
A5-14-1	9	7.3	0.51	13.0	1.50	7/9	7/9
A3-7X14-2	9	6.8	0.79	10.5	1.51	9/9	9/9
A7-00-2	9	5.4	0.44	10.0	2.89	8/9	9/9
13-16-1 (Kapton)	9	5.1	0.25	6.7	0.25	9/9	9/9

*N = Number of experimental animals exposed.

†SD = Standard deviation.

‡Mean values were calculated only for those animals with response times ≤30 min, and then only if responses were obtained for >65 percent of the exposed population.

§Loss response times are for the 750F condition.

∫S = 14-day survival.

TABLE 11. OBSERVED RESPONSE TIMES, HIGH TEMPERATURE, FLAMING CONDITION

Material No.	N*	Mean‡ Obs t_i, Min	SD†	Mean‡ Obs t_d, Min	SD†	Mortality 30-Min	Mortality 14-Day
A6-4X12-1	9	--	--	S[ʃ]	--	0/9	0/9
1-16-1 (Silicone/PO)	9	17.7	1.43	S	--	0/9	0/9
12-20-2 (Teflon)	12	8.2	4.32	>30	--	7/12	12/12
A7-00-2	9	7.4	0.85	12.7	1.97	9/9	9/9
A1-14-1 (PVC)	9	7.3	0.65	12.8	2.16	9/9	9/9
A2-6/2X19-4	9	7.3	0.42	11.7	1.38	9/9	9/9
A7-24X19-5	9	7.3	0.69	11.4	1.13	9/9	9/9
A5-00-3	9	7.2	0.47	12.5	1.76	9/9	9/9
11-20-1 (Exane)	9	7.0	0.49	10.5	0.77	9/9	9/9
A5-14-1	9	6.3	0.44	11.1	1.80	9/9	9/9
A3-7X14-2	9	5.9	0.63	10.9	2.19	9/9	9/9
12-12-4 (Halar)[§]	9	4.7	0.40	6.4	0.99	9/9	9/9
3-20-1 (Tefzel)	9	4.5	1.54	12.3	4.24	8/9	9/9
13-16-1 (Kapton)	9	4.5	0.57	8.8	1.84	9/9	9/9

*N = Number of experimental animals exposed.

†SD = Standard deviation.

‡Mean values were calculated only for those animals with response times ≤ 30 min, and then only if responses were obtained for >65 percent of the exposed population.

§Observed response times are for the 750NF condition.

ʃS = 14-day survival.

TABLE 12. STANDARD RESPONSE TIMES, HIGH TEMPERATURE, FLAMING CONDITION

Material No.	N*	Mean‡ Std t_i, Min	SD†	Mean‡ Std t_d, Min	SD†	Mortality 30-Min	Mortality 14-Day
A6-4X12-1	9	--	--	S∫	--	0/9	0/9
1-16-1 (Silicone/PO)	9	17.9	1.58	S	--	0/9	0/9
12-20-2 (Teflon)	12	8.3	4.43	>30	--	7/12	12/12
A7-24X19-5	9	7.5	0.83	11.9	1.19	9/9	9/9
A5-00-3	9	7.4	0.61	12.9	2.37	9/9	9/9
A1-14-1 (PVC)	9	7.4	0.36	12.9	2.07	9/9	9/9
A2-6/2X19-4	9	7.4	0.53	12.0	1.75	9/9	9/9
A7-00-2	9	7.3	0.74	12.6	2.24	9/9	9/9
11-20-1 (Exane)	9	7.0	0.37	10.4	0.60	9/9	9/9
A5-14-1	9	6.6	0.44	11.5	1.66	9/9	9/9
A3-7X14-2	9	6.0	0.41	11.1	2.21	9/9	9/9
12-12-4 (Halar)§	9	4.7	0.53	6.5	1.23	9/9	9/9
3-20-1 (Tefzel)	9	4.5	1.48	12.4	4.09	8/9	9/9
13-16-1 (Kapton)	9	4.5	0.61	8.6	1.83	9/9	9/9

*N = Number of experimental animals exposed.

†SD = Standard deviation.

‡Mean values were calculated only for those animals with response times ≤30 min, and then only if responses were obtained for >65 percent of the exposed population.

§Standard response times are for the 750NF condition.

∫S = 14-day survival.

TABLE 13. LOSS RESPONSE TIMES, HIGH TEMPERATURE, FLAMING CONDITION

Material No.	N*	Mean‡ Loss t_i, Min	SD†	Mean‡ Loss t_d, Min	SD†	Mortality 30-Min	Mortality 14-Day
A6-4X12-1	9	--	--	S∫	--	0/9	0/9
12-20-2 (Teflon)	12	8.3	4.43	>30	--	7/12	12/12
1-16-1 (Silicone/PO)	9	7.5	1.50	S	--	0/9	0/9
A2-6/2X19-4	9	7.4	0.53	12.0	1.75	9/9	9/9
A1-14-1 (PVC)	9	6.7	0.32	11.8	1.99	9/9	9/9
A7-24X19-5	9	6.5	0.69	10.2	1.01	9/9	9/9
11-20-1 (Exane)	9	6.0	0.30	8.9	0.50	9/9	9/9
A3-7X14-2	9	4.9	0.35	8.9	1.76	9/9	9/9
A5-00-3	9	4.9	0.40	8.6	1.58	9/9	9/9
12-12-4 (Halar)§	9	4.7	0.53	6.5	1.23	9/9	9/9
A7-00-2	9	4.6	0.47	7.9	1.41	9/9	9/9
3-20-1 (Tefzel)	9	4.5	1.48	12.4	4.09	8/9	9/9
A5-14-1	9	3.8	0.23	6.7	0.96	9/9	9/9
13-16-1 (Kapton)	9	3.3	0.44	6.4	1.30	9/9	9/9

*N = Number of experimental animals exposed.

†SD = Standard deviation.

‡Mean values were calculated only for those animals with response times ≥30 min, and then only if responses were obtained for >65 percent of the exposed population.

§Loss response times are for the 750NF condition.

∫S = 14-day survival.

TABLE 14. MATERIAL RANK-ORDER BASED ON WORST CASE PERFORMANCE FOR OBSERVED t_i

Rank*	Material No.	Thermal Condition†	N‡	Mean Obs t_i, Min	SD§
1	A6-4X12-1	LTNF	9	21.9ʃ	5.36
2	1-16-1 (Silicone/PO)	HTF	9	17.7	1.43
3	A7-00-2	HTF	9	7.4	0.85
4	A7-24X19-5	HTF	9	7.3	0.69
5	A1-14-1 (PVC)	HTF	9	7.3	0.65
6	A5-00-3	HTF	9	7.2	0.47
7	11-20-1 (Exane)	HTF	9	7.0	0.49
8	A2-6/2X19-4	LTNF	9	6.8	0.36
9	12-20-2 (Teflon)	LTNF	9	6.7	1.70
10	A5-14-1	HTF	9	6.3	0.44
11	A3-7X14-2	HTF	9	5.9	0.63
12	12-12-4 (Halar)	750NF	9	4.7	0.40
13	3-20-1 (Tefzel)	HTF	9	4.5	1.54
14	13-16-1 (Kapton)	HTF	9	4.5	0.57

*Rank 1 is least toxic.

†LTNF = low temperature nonflaming; HTF = high temperature flaming; 750NF = 750°C, nonflaming.

‡N = Number of experimental animals exposed.

§SD = Standard deviation.

ʃN = 8; one animal did not incapacitate in 30 min.

TABLE 15. MATERIAL RANK-ORDER BASED ON WORST CASE PERFORMANCE FOR STANDARD t_i

Rank*	Material No.	Thermal Condition†	N‡	Mean Std t_i, Min	SD§
1	A6-4X12-1	LTNF	9	22.0∫	4.84
2	1-16-1 (Silicone/PO)	HTF	9	17.9	1.58
3	A7-24X19-5	HTF	9	7.5	0.83
4	A1-14-1 (PVC)	HTF	9	7.4	0.36
5	A5-00-3	HTF	9	7.4	0.61
6	A7-00-2	HTF	9	7.3	0.74
7	11-20-1 (Exane)	HTF	9	7.0	0.37
8	A2-6/2X19-4	LTNF	9	6.9	0.28
9	12-20-2 (Teflon)	LTNF	9	6.7	1.70
10	A5-14-1	HTF	9	6.6	0.44
11	A3-7X14-2	HTF	9	6.0	0.41
12	12-12-4 (Halar)	750NF	9	4.7	0.53
13	3-20-1 (Tefzel)	HTF	9	4.5	1.48
14	13-16-1 (Kapton)	HTF	9	4.5	0.61

*Rank 1 is least toxic.

†LTNF = low temperature nonflaming; HTF = high temperature flaming; 750NF = 750°C, nonflaming.

‡N = Number of experimental animals exposed.

§SD = Standard deviation.

∫N = 8; one animal did not incapacitate in 30 min.

TABLE 16. MATERIAL RANK-ORDER ON WORST CASE PERFORMANCE FOR LOSS t_i

Rank*	Material No.	Thermal Condition†	N‡	Mean Std t_i, Min	SD§
1	1-16-1 (Silicone/PO)	LTNF/HTF	9	7.4	0.34
2	A6-4X12-1	LTNF	9	7.3∫	1.28
3	12-20-2 (Teflon)	LTNF	9	6.7	1.70
4	A1-14-1 (PVC)	HTF	9	6.7	0.32
5	A2-6/2X19-4	LTNF	9	6.7	0.28
6	A7-24X19-5	HTF	9	6.5	0.69
7	11-20-1 (Exane)	HTF	9	6.0	0.30
8	A3-7X14-2	HTF	9	4.9	0.35
9	A5-00-3	HTF	9	4.9	0.40
10	12-12-4 (Halar)	750NF	9	4.7	0.53
11	A7-00-2	HTF	9	4.6	0.47
12	3-20-1 (Tefzel)	HTF	9	4.5	1.48
13	A5-14-1	HTF	9	3.8	0.23
14	13-16-1 (Kapton)	HTF	9	3.3	0.44

*Rank 1 is least toxic.

†LTNF = low temperature nonflaming; HTF = high temperature flaming; 750NF = 750°C, nonflaming.

‡N = Number of experimental animals exposed.

§SD = Standard deviation.

∫N = 8; one animal did not incapacitate in 30 min.

TABLE 17. RANK-ORDER EVALUATIONS OF TOXICITY BASED ON A CALCULATED t_i' (WORST CASE PERFORMANCE) FOR INSULATIONS FROM EQUAL-GAUGE WIRE ASSEMBLIES*

Rank†	Insulation Material	Thermal Mode‡	t_i x a/100, Per Assembly, Min (x100)§	SD∫	No. of Conductors per Assembly	AWG	t_i x $\frac{ab}{100}$ Per conductor, Min (x100)
1	3-20-1 (Tefzel)	HTF	260	86	1	20	260
2	12-20-2 (Teflon)	LTNF	190	48	1	20	190
3	11-20-1 (Exane)	HTF	100	5.0	1	20	100
1	A2-6/2X19-4	LTNF	4.7	0.20	12	19	56
2	A7-24X19-5	HTF	1.1	0.12	24	19	27
1	13-16-1 (Kapton)	HTF	270	37	1	16	270
2	1-16-1 (Silicone/PO)	LTNF	136	7.0	1	16	136
1	A1-14-1 (PVC)	HTF	180	6.0	1	14	180
2	A5-14-1	HTF	38	2.3	1	14	38
3	A3-7X14-2	HTF	0.90	0.06	7	14	6.3
1	A6-4X12-1	LTNF	18→	4.0	4	12	72
2	12-12-4 (Halar)	750NF	57	7.0	1	12	57
1	A7-00-2	HTF	4.3	0.41	1	2/0	4.3
2	A5-00-3	HTF	1.9	0.15	1	2/0	1.9

*Only those wire assemblies containing equal-gauge conductors are ranked as to relative toxicity.

†Rank 1 is least toxic; relative rank is based on the calculated response time for that quantity of material from one meter of insulation from one conductor per assembly (last column).

‡HTF = high temperature flaming; LTNF = low temperature nonflaming; 750NF = 750°C, nonflaming.

§Nine animals were exposed per material.

∫SD = standard deviation.

→Mean value is for eight animals; one animal did not incapacitate within the 30-min exposure.

APPENDIX A
PRIMARY DATA, ALL TEST MODES

TABLE A-1. PRIMARY DATA FROM LOW TEMPERATURE, NONFLAMING TESTS

Temp, °C	Sample Wt, g	Sample Loss, g	Time to Visible Smoke, min	Max Smoke Density, OD	Time to Smoke Peak, min	Max CO, ppm	Time to Max CO, min	t_i, Obs, min	t_d, Obs, min
11-20-1 (Exane)									
550	1.0010	0.814	0.65	0.40	2.2	3360	4.6	13.3	17.5
								15.7	27.5
								13.8	25.5
550	1.0016	0.819	0.77	0.45	2.5	3200	6.4	14.3	2D*
								14.6	28.9
								15.8	1D
550	1.0017	0.833	0.99	0.43	2.6	3410	4.6	12.5	25.9
								11.3	21.4
								12.7	1D
12-12-4 (Halar)									
600	0.9991	0.999	0.97	0.26	1.5	17675	8.3	5.4	6.5
								5.7	7.4
								5.5	7.2
600	0.9995	0.999	1.11	0.25	1.6	30300	10.2	5.8	8.0
								5.8	7.6
								6.0	8.3
600	1.0016	1.002	1.00	0.25	1.7	29660	10.2	5.8	8.1
								5.7	7.8
								6.3	8.2

*D = Days survived.

TABLE A-1. PRIMARY DATA, LTNF TESTS--Continued

Temp, °C	Sample Wt, g	Sample Loss, g	Time to Visible Smoke, min	Max Smoke Density, OD	Time to Smoke Peak, min	Max CO, ppm	Time to Max CO, min	t_i, Obs, min	t_d, Obs, min
13-16-1 (Kapton)									
650	1.0000	0.653	1.56	0.04	3.5	18675	10.2	7.8	9.2
								7.9	9.7
								8.0	9.8
650	1.0001	0.619	1.27	0.03	2.9	18126	8.3	6.5	8.7
								6.2	8.3
								6.4	8.1
650	1.0014	0.659	1.15	0.03	2.4	17935	8.3	6.6	7.5
								6.6	7.9
								6.7	8.3
1-16-1 (Silicone Rubber/Polyolefin)									
550	1.0013	0.401	0.73	0.19	2.0	5046	6.4	18.4	27.5
								19.6	38.2
								19.5	32.1
550	0.9997	0.395	0.78	0.22	2.9	2537	8.3	20.2	S†
								20.3	S
								21.6	S
550	1.0001	0.402	0.88	0.21	2.7	2393	6.4	17.3	36
								19.3	S
								17.9	S

†S = Survived 14 days.

TABLE A-1. PRIMARY DATA, LTNF TESTS--Continued

Temp, °C	Sample Wt, g	Sample Loss, g	Time to Visible Smoke, min	Max Smoke Density, OD	Time to Smoke Peak, min	Max CO, ppm	Time to Max CO, min	t_i, Obs, min	t_d, Obs, min
12-20-2 (Teflon)									
650	1.0003	1.000	1.53	0.16	2.8	911	6.4	6.4	25.4
								6.0	26.3
								6.1	14.7
650	1.0001	1.000	1.81	0.16	3.8	692	6.4	9.1	45
								8.9	23.3
								8.4	13.6
650	1.0010	1.001	1.51	0.20	3.2	692	2.7	5.0	120
								5.1	120
								4.9	2D*
8-20-1 (Tefzel)									
550	0.9994	0.936	1.70	0.17	3.4	9947	10.2	9.9	12.4
								9.7	11.9
								9.5	11.6
550	0.9997	0.877	1.80	0.15	3.6	8840	10.2	11.3	16.1
								11.1	14.4
								11.1	14.1
550	1.0006	0.863	2.9	0.12	4.4	8020	10.2	11.4	15.8
								11.7	13.7
								11.1	14.3

*D = Days survived.

TABLE A-1. PRIMARY DATA, LTNF TESTS--Continued

Temp, °C	Sample Wt, g	Sample Loss, g	Time to Visible Smoke, min	Max Smoke Density, OD	Time to Smoke Peak, min	Max CO, ppm	Time to Max CO, min	t_i, Obs, min	t_d, Obs, min
A1-14-1 (PVC)									
550	0.9995	0.889	0.60	0.24	1.4	2427	10.2	19.4	S†
								23.8	S
								24.3	S
550	1.0011	0.895	0.60	0.31	2.0	2686	10.2	19.7	29.0
								20.3	4D
								19.9	S
550	1.0007	0.891	0.56	0.29	2.0	2460	8.3	22.5	3D
								20.9	S
								19.7	S
A7-00-2									
550	0.9996	0.597	0.73	0.34	2.2	7201	8.3	9.1	12.2
								8.4	11.1
								9.0	13.0
550	0.9994	0.597	0.82	0.39	2.1	8025	6.4	8.5	11.4
								9.6	13.8
								9.9	15.3
550	1.0004	0.596	0.81	0.39	2.4	7555	8.3	8.9	12.7
								9.9	14.3
								9.1	13.0

*D = Days survived.

†S = Survived 14 days.

TABLE A-1. PRIMARY DATA, LTNF TESTS--Continued

Temp, °C	Sample Wt, g	Sample Loss, g	Time to Visible Smoke, min	Max Smoke Density, OD	Time to Smoke Peak, min	Max CO, ppm	Time to Max CO, min	t_i, Obs, min	t_d, Obs, min
A3-7X14-2									
550	1.0016	0.775	0.61	0.42	2.0	5531	6.4	11.1	17.5
								9.4	12.6
								8.9	16.4
550	1.0011	0.784	0.82	0.55	2.4	5734	8.3	11.5	15.3
								11.6	16.0
								13.0	21.5
550	1.0019	0.783	0.69	0.49	1.9	6090	6.4	10.7	13.8
								11.4	15.6
								9.7	12.7
A5-00-3									
475	1.0021	0.659	1.61	0.36	5.0	4833	8.3	14.2	18.9
								11.7	20.1
								12.1	16.9
475	0.9990	0.646	1.65	0.36	5.6	4529	8.3	15.1	31.0
								12.4	15.8
								13.6	20.8
475	0.9991	0.649	2.14	0.39	5.4	4842	10.2	12.9	21.3
								13.7	21.3
								12.7	20.3

TABLE A-1. PRIMARY DATA, LTNF TESTS--Continued

Temp, °C	Sample Wt , g	Sample Loss, g	Time to Visible Smoke, min	Max Smoke Density, OD	Time to Smoke Peak, min	Max CO, ppm	Time to Max CO, min	t_i, Obs, min	t_d, Obs, min
A5-14-1									
550	1.0030	0.582	0.97	0.43	2.8	3781	6.4	12.5	21.9
								13.3	19.2
								11.6	19.2
550	1.0006	0.616	1.00	0.40	2.8	4222	6.4	14.8	18.9
								14.1	20.1
								12.7	15.4
550	1.0020	0.577	0.94	0.39	2.8	3698	6.4	14.6	19.0
								12.2	16.7
								16.1	24.0
A6-4X12-1									
550	1.0007	0.369	0.65	0.13	4.4	2238	10.2	15.7	19.1
								17.7	23.2
								22.5	34
550	1.0001	0.333	0.74	0.09	3.0	1819	10.2	15.7	19.2
								22.3	25.7
								22.8	26.1
550	1.0005	0.301	0.84	0.11	3.6	1595	10.2	NI‡	3D*
								29.0	36
								29.3	36

* D = Days survived

‡ NI= Not incapacitated

TABLE A-1. PRIMARY DATA, LTNF TESTS--Continued

Temp, °C	Sample Wt, g	Sample Loss, g	Time to Visible Smoke, min	Max Smoke Density, OD	Time to Smoke Peak, min	Max CO, ppm	Time to Max CO, min	t_i, Obs, min	t_d, Obs, min
A7-24X19-5									
500	1.0038	0.835	0.96	0.28	3.8	8169	6.4	8.1	10.9
								8.0	10.4
								8.3	12.7
500	1.0107	0.836	1.55	0.32	4.0	8585	6.4	8.0	11.4
								7.3	9.5
								7.9	12.1
500	1.0068	0.841	1.29	0.22	4.4	8681	8.3	8.8	12.5
								8.4	10.6
								8.6	10.9
A2-6/2X19-4									
475	0.9996	0.973	2.02	0.20	4.4	13511	8.3	7.1	10.7
								6.4	8.5
								6.4	8.5
475	1.0014	0.992	1.96	0.36	4.2	13279	8.3	6.5	8.7
								6.5	8.8
								6.9	9.6
475	1.0018	0.984	1.90	0.36	5.0	13150	10.2	6.9	8.4
								7.0	9.8
								7.4	10.3

TABLE A-2. PRIMARY DATA FROM LOW TEMPERATURE FLAMING TESTS

Temp, °C	Sample Wt, g	Sample Loss, g	Time to Visible Smoke, min	Max Smoke Density, OD	Time to Smoke Peak, min	Max CO, ppm	Time to Max CO, min	t_i, Obs, min	t_d, Obs, min
11-20-1 (Exane)									
550	1.0013	0.804	0.68	0.28	1.7	7250	6.4	9.4	34
								10.0	21.4
								10.2	15.8
550	1.0013	0.826	0.88	0.29	1.9	5550	4.6	9.7	21.2
								8.0	14.4
								8.6	14.4
550	1.0016	0.806	0.76	0.40	2.1	4760	4.6	9.9	30.3
								10.4	29.0
								10.8	26.5
12-12-4 (Halar)(750F)									
750	1.0007	1.001	0.60	0.45	0.8	8140	4.6	7.9	11.8
								6.2	10.8
								7.0	11.1
750	1.0014	1.001	0.48	0.56	0.9	7430	2.7	8.4	13.9
								6.7	11.6
								8.6	15.8
750	1.0018	1.002	0.58	0.39	1.0	7090	4.6	8.8	12.5
								8.6	13.5
								8.8	13.7

TABLE A-2. PRIMARY DATA, LTF TESTS--Continued

Temp, °C	Sample Wt, g	Sample Loss, g	Time to Visible Smoke, min	Max Smoke Density, OD	Time to Smoke Peak, min	Max CO, ppm	Time to Max CO, min	t_i, Obs, min	t_d, Obs, min
13-16-1 (Kapton)									
650	0.9997	0.720	1.08	0.05	3.1	14164	10.2	7.7	9.9
								7.8	9.8
								7.1	9.4
650	1.0004	0.598	1.35	0.05	3.1	14875	12.1	7.6	10.5
								7.8	9.8
								7.9	11.2
650	1.0009	0.674	1.31	0.01	3.0	13952	10.2	7.8	10.3
								7.8	9.6
								8.0	10.3
1-16-1 (Silicone Rubber/Polyolefin)[§]									
550	0.9988	0.387	0.95	0.03	1.6	1234	6.4	NI[‡]	S[†]
								NI	S
								NI	S
550	0.9994	0.381	0.68	0.05	2.2	771	6.4	NI	S
								NI	S
								NI	S

[†]S = Survived 14 days.

[‡]NI = Not incapacitated.

[§]Only two tests (six animals) were conducted at 550°/flaming since no response was noted at 30 minutes (t_i) or 14 days (t_d).

TABLE A-2. PRIMARY DATA, LTF TESTS--Continued

Temp, °C	Sample Wt, g	Sample Loss, g	Time to Visible Smoke, min	Max Smoke Density OD	Time to Smoke Peak, min	Max CO, ppm	Time to Max CO, min	t_i, Obs, min	t_d, Obs min
12-2-2 (Teflon)									
650	0.9997	1.000	1.15	0.32	1.88	1391	2.7	10.8	13.2
								11.3	15.7
								12.4	33.2
650	1.0009	1.001	1.45	0.18	3.10	1405	4.6	8.4	S†
								8.5	S
								9.1	S
650	1.0008	1.001	1.56	0.24	3.30	1560	4.6	10.9	1D
								15.4	39.4
								10.6	16.0
650	1.0007	1.001	1.77	0.26	3.60	1483	4.6	11.5	200
								12.8	200
								12.8	37
3-20-1 (Tefzel)									
550	1.0001	0.915	1.98	0.18	3.8	7580	10.2	11.2	13.8
								11.1	14.6
								11.0	13.7
550	1.0011	0.930	1.86	0.20	3.8	9880	10.2	10.4	13.9
								10.4	12.0
								10.5	13.6
550	0.9996	0.944	1.50	0.27	3.2	11480	10.2	9.9	12.4
								9.6	11.8
								9.7	12.5

†S = Survived 14 days.

TABLE A-2. PRIMARY DATA, LTF TESTS--Continued

Temp, °C	Sample Wt, g	Sample Loss, g	Time to Visible Smoke, min	Max Smoke Density, OD	Time to Smoke Peak, min	Max CO, ppm	Time to Max CO, min	t_i, Obs, min	t_d, Obs, min
A1-14-1(PVC)									
550	1.0009	0.888	0.56	0.27	1.3	3819	4.6	10.9	21.1
								11.1	14.8
								10.9	18.0
550	1.0004	0.896	0.78	0.27	1.4	4349	6.4	12.1	26.9
								13.6	36
								12.3	30.2
550	1.0000	0.895	0.67	0.25	1.8	4104	6.4	13.0	33
								12.5	19.2
								12.0	18.6
A7-00-2									
550	0.9971	0.592	0.87	0.12	1.8	5185	6.4	10.0	20.4
								9.7	28.1
								10.5	30.1
550	1.0008	0.592	0.79	0.22	1.6	6868	4.6	9.1	15.4
								9.0	16.7
								8.0	10.8
550	0.9990	0.595	1.00	0.10	1.6	5562	6.4	9.6	17.6
								9.4	14.4
								9.7	17.2

TABLE A-2. PRIMARY DATA, LTF TESTS--Continued

Temp, °C	Sample Wt, g	Sample Loss, g	Time to Visible Smoke, min	Max Smoke Density, OD	Time to Smoke Peak, min	Max CO, ppm	Time to Max CO, min	t_i, Obs, min	t_d, Obs, min
A3-7X14-2									
550	1.0003	0.769	0.72	0.30	1.6	6164	4.6	9.0	12.6
								9.6	13.7
								10.7	17.7
550	1.0017	0.780	0.60	0.25	1.8	7100	4.6	8.3	13.6
								8.7	12.4
								7.7	13.1
550	1.0006	0.787	0.88	0.26	2.0	6471	6.4	8.8	12.7
								9.5	14.7
								8.9	13.9
A5-00-3									
475	0.9994	0.656	1.47	0.07	4.0	3385	10.2	13.5	23.0
								14.1	S†
								14.2	34
475	1.0004	0.655	2.43	0.12	4.4	3580	8.3	18.8	S
								18.1	35
								18.7	39
475	0.9983	0.657	2.25	0.10	4.0	3535	10.2	14.6	S
								15.2	24.6
								13.7	24.6

† S = Survived 14 days.

TABLE A-2. PRIMARY DATA, LTF TESTS--Continued

Temp, °C	Sample Wt, g	Sample Loss, g	Time to Visible Smoke, min	Max Smoke Density, OD	Time to Smoke Peak, min	Max CO, ppm	Time to Max CO, min	t_i, Obs, min	t_d, Obs, min
A5-14-1									
550	1.0011	0.575	0.97	0.07	1.3	4082	4.6	12.8	19.6
								13.9	21.7
								11.7	21.6
550	0.9987	0.575	1.06	0.07	2.8	4663	4.6	12.5	24.8
								13.7	S†
								12.7	21.1
550	1.0011	0.579	1.23	0.08	2.6	4198	4.6	14.4	28.2
								14.3	S
								13.1	28.8
A6-4X12-1									
550	1.0008	0.240	0.62	0.02	0.8	1309	4.6	NI‡	S
								NI	S
								NI	S
550	1.0017	0.301	1.08	0.12	3.2	1815	6.4	NI	S
								NI	S
								NI	S
550	1.0009	0.250	0.73	0.05	2.1	1127	4.6	NI	S
								NI	S
								NI	S

†S = Survived 14 days.

‡NI = Not incapacitated.

TABLE A-2. PRIMARY DATA, LTF TESTS--Continued

Temp, °C	Sample Wt, g	Sample Loss, g	Time to Visible Smoke, min	Max Smoke Density, OD	Time to Smoke Peak, min	Max CO, ppm	Time to Max CO, min	t_i, Obs, min	t_d, Obs, min
A7-24X19-5									
500	1.0005	0.846	0.88	0.12	2.6	4448	2.7	13.3	S[†]
								12.0	21.8
								13.7	22.7
500	1.0108	0.854	1.19	0.16	2.8	5172	4.6	11.2	27.6
								11.5	19.5
								12.0	20.3
500	1.0142	0.852	1.01	0.10	2.8	5620	4.6	12.1	22.2
								11.0	16.8
								12.0	16.5
A2-6/2X19-4									
475	1.0010	0.985	1.82	0.28	4.4	6457	4.6	9.6	13.5
								12.3	16.6
								8.4	18.0
475	1.0015	0.986	2.60	0.23	4.4	5960	4.6	10.4	16.0
								10.8	17.7
								10.3	19.3
475	1.0011	0.991	2.25	0.24	4.0	6240	4.0	11.1	19.3
								11.9	19.7
								10.8	17.6

[†]S = Survived 14 days.

TABLE A-3. PRIMARY DATA FROM HIGH TEMPERATURE FLAMING TESTS

Temp, °C	Sample Wt, g	Sample Loss, g	Time to Visible Smoke, min	Max Smoke Density, OD	Time to Smoke Peak, min	Max CO, ppm	Time to Max CO, min	t_i, Obs, min	t_d, Obs min
11-20-1 (Exane)									
750	1.0014	0.853	0.20	0.56	0.60	8010	6.4	7.4	10.9
								7.1	11.2
								6.9	11.2
750	1.0012	0.852	0.37	0.65	0.90	9280	4.6	7.6	10.7
								6.7	9.5
								7.3	10.6
750	1.0016	0.856	0.30	0.56	0.90	9840	6.4	7.3	11.2
								6.2	9.7
								6.6	9.3
12-12-4 (Halar) (750NF)									
750	1.0006	1.001	0.50	0.38	0.80	15934	4.6	5.0	5.9
								4.2	5.4
								4.3	6.0
750	1.0001	1.000	0.56	0.42	0.90	15280	4.6	4.6	6.5
								4.4	8.8
								4.4	5.7
750	1.0006	1.001	0.56	0.42	0.90	16310	4.6	4.7	6.4
								5.2	6.7
								5.3	6.6

TABLE A-3. PRIMARY DATA, HTF TESTS--Continued

Temp, °C	Sample Wt, g	Sample Loss, g	Time to Visible Smoke, min	Max Smoke Density, OD	Time to Smoke Peak, min	Max CO, ppm	Time to Max CO, min	t_i, Obs, min	t_d, Obs, min
13-16-1 (Kapton)									
750	0.9998	0.745	0.72	0.02	1.1	8010	2.7	4.0	8.4
								4.0	6.2
								3.9	6.1
750	1.0006	0.706	0.93	0.01		7010	2.7	5.1	10.4
								5.3	9.8
								4.8	11.3
750	1.0000	0.755	0.77	0.02	1.4	8684	2.7	4.0	7.5
								5.1	9.7
								4.6	9.6
1-16-1 (Silicone Rubber/Polyolefin)									
750	0.9996	0.393	0.47	0.16	1.3	2501	6.4	16.9	S†
								16.9	S
								16.9	S
750	1.0011	0.482	0.38	0.10	1.2	2324	6.4	20.1	S
								18.9	S
								19.6	S
750	1.0008	0.382	0.36	0.12	1.4	2398	6.4	16.9	S
								16.7	S
								16.3	S

†S = Survived 14 days.

TABLE A-3. PRIMARY DATA, HTF TESTS--Continued

Temp, °C	Sample Wt, g	Sample Loss, g	Time to Visible Smoke, min	Max Smoke Density, OD	Time to Smoke Peak, min	Max CO, ppm	Time to Max CO, min	t_i, Obs, min	t_d, Obs, min
12-20-2 (Teflon)									
750	1.0014	1.001	0.81	0.10	1.90	2144	10.2	4.0	15.4
								3.9	6.7
								10.0	36
750	1.0001	1.000	0.68	0.18	1.80	2064	2.7	3.2	29.6
								4.3	45
								4.0	34
750	1.0007	1.001	0.84	0.20	1.80	1580	2.7	8.7	35
								8.8	12.4
								9.6	37
750	1.0002	1.000	0.96	0.25	1.80	1569	4.6	15.4	24.8
								12.3	20.1
								14.3	23.0
3-20-1 (Tefzel)									
750	0.9998	1.000	0.45	0.29	1.2	5847	2.7	5.8	20.4
								4.6	10.0
								3.5	10.0
750	0.9999	1.000	0.51	0.20	1.2	>7000	4.6	2.5	9.4
								3.0	9.2
								2.9	9.1
750	1.0009	1.001	0.50	0.30	1.4	4148	4.6	6.7	30.5
								5.6	13.3
								5.7	16.8

TABLE A-3. PRIMARY DATA, HTF TESTS--Continued

Temp, °C	Sample Wt, g	Sample Loss, g	Time to Visible Smoke, min	Max Smoke Density, OD	Time to Smoke Peak, min	Max CO, ppm	Time to Max CO, min	t_i, Obs, min	t_d, Obs, min
A1-14-1 (PVC)									
750	1.0004	0.906	0.24	0.40	0.7	6458	4.6	8.1	15.8
								8.2	14.6
								8.2	11.3
750	1.0007	0.907	0.25	0.29	1.0	7312	6.4	7.0	14.2
								6.9	9.7
								7.0	15.1
750	1.0040	0.910	0.44	0.34	1.0	7601	6.4	6.6	11.5
								7.0	12.7
								6.9	10.7
A7-00-2									
750	1.0009	0.630	0.46	0.34	1.2	8704	4.6	6.7	11.1
								6.6	9.2
								6.8	10.8
750	1.0014	0.627	0.38	0.16	1.0	6200	6.4	6.6	14.2
								7.4	13.2
								7.3	12.4
750	1.0005	0.632	0.48	0.25	1.1	7059	4.6	8.2	15.1
								9.1	13.5
								7.7	14.6

TABLE A-3. PRIMARY DATA, HTF TESTS--Continued

Temp, °C	Sample Wt, g	Sample Loss, g	Time to Visible Smoke, min	Max Smoke Density, OD	Time to Smoke Peak, min	Max CO, ppm	Time to Max CO, min	t_i, Obs, min	t_d, Obs, min
A3-7X14-2									
750	1.0000	0.801	0.35	0.31	0.9	10046	4.6	5.8	10.0
								5.5	15.9
								5.5	12.0
750	1.0006	0.813	0.32	0.28	1.0	9623	4.6	6.8	10.4
								6.7	12.0
								6.7	9.6
750	1.0011	0.802	0.36	0.26	1.0	9850	6.4	5.1	8.7
								5.8	10.5
								5.6	9.1
A5-00-3									
750	1.0019	0.667	0.70	0.39	1.2	8329	6.4	7.1	10.8
								7.8	11.1
								6.6	10.1
750	0.9987	0.665	0.59	0.17	1.6	6864	6.4	7.0	16.0
								6.8	12.2
								7.1	12.7
750	1.0012	0.661	0.66	0.20	1.4	8240	6.4	7.1	12.8
								7.1	12.7
								8.1	13.8

TABLE A-3. PRIMARY DATA, HTF TESTS--Continued

Temp, °C	Sample Wt, g	Sample Loss, g	Time to Visible Smoke, min	Max Smoke Density, OD	Time to Smoke Peak, min	Max CO, ppm	Time to Max CO, min	t_i, Obs, min	t_d, Obs, min
A5-14-1									
750	1.0000	0.575	0.36	0.15	1.4	7981	4.6	6.1	11.4
								6.3	14.0
								7.0	14.0
750	0.9977	0.575	0.27	0.15	1.4	7650	4.6	6.4	10.8
								5.9	10.4
								6.1	9.9
750	0.9999	0.576	0.46	0.16	1.6	8170	6.4	6.0	10.3
								5.8	8.6
								7.0	10.7
A6-4X12-1									
750	1.0005	0.312	0.40	0.07	1.0	1488	4.6	NI‡	S†
								NI	S
								NI	S
750	1.0000	0.309	0.25	0.05	1.2	1008	4.6	NI	S
								NI	S
								NI	S
750	1.0006	0.313	0.54	0.05	1.6	1035	6.4	NI	S
								NI	S
								NI	S

†S = Survived 14 days.

‡NI = Not incapacitated.

TABLE A-3. PRIMARY DATA, HTF TESTS--Continued

Temp, °C	Sample Wt, g	Sample Loss, g	Time to Visible Smoke, min	Max Smoke Density, OD	Time to Smoke Peak, min	Max CO, ppm	Time to Max CO, min	t_i, Obs, min	t_d, Obs, min
A7-24X19-5									
750	1.0074	0.878	0.37	0.42	1.2	8036	6.4	7.3	12.5
								7.3	11.1
								7.4	11.9
750	1.0067	0.869	0.34	0.45	1.2	6864	8.3	7.4	11.3
								7.4	11.2
								7.1	11.1
750	0.9997	0.857	0.54	0.39	1.2	7750	8.3	6.7	11.5
								6.1	9.1
								8.7	13.2
A2-6/2X19-4									
750	1.0007	0.999	0.52	0.48	1.2	8386	8.3	7.4	12.2
								7.3	9.4
								7.3	10.9
750	1.0005	0.998	0.49	Lost	--	6512	8.3	7.2	10.9
								6.8	14.1
								8.0	12.9
750	0.9980	0.997	0.63	0.50	1.4	8344	10.2	7.4	12.5
								7.5	11.7
								6.5	10.9

APPENDIX B
PRELIMINARY DATA USED TO ESTABLISH TEST MODE PARAMETERS

TABLE B-1. PRELIMINARY TESTS TO ESTABLISH THERMAL DEGRADATION CONDITIONS

Mode ∫	Temp, °C	Sample Wt g	Sample Loss, g	Time to Visible Smoke, min	Max Smoke Density, OD	Time to Smoke Peak, min	Max CO, ppm	Time to Max CO, min	t_i, Obs, min	t_d, Obs, min
11-20-1 (Exane)										
NF	550	0.7511	0.641	0.59	0.45	1.7	3150	4.6	16.5	35
									16.6	27.2
									16.2	2D*
F	550	0.7497	0.627	0.78	0.27	1.4	3950	4.6	13.4	33.8
									14.0	29.8
									14.4	29.2
NF	575	0.7486	0.637	0.60	0.42	1.7	2760	4.6	13.2	2D
									12.2	27.5
									16.1	2D
F	600	0.7516	0.632	0.63	0.22	1.4	4870	4.6	11.4	23.8
									11.5	26.7
									11.3	23.3
12-12-4 (Halar)										
NF	550	0.7514	0.751	0.98	0.27	1.4	13710	10.2	5.9	9.2
									5.6	8.3
									6.4	9.8
NF	550	0.7532	0753	0.95	0.13	1.9	15120	6.4	6.4	8.5
									6.4	8.7
									6.2	8.2
NF	600	0.7519	0.752	1.05	0.26	1.6	13620	6.4	6.1	8.4
									6.1	8.2
									5.9	7.8
F	600	0.7515	0.751	0.85	0.19	1.2	15630	4.6	5.2	6.9
									4.8	6.7
									4.7	7.3

* D = Days survived.
∫ F = Flaming; NF = Nonflaming.

TABLE B-1. PRELIMINARY TESTS--Continued

Mode ∫	Temp, °C	Sample Wt, g	Sample Loss, g	Time to Visible Smoke, min	Max Smoke Density, OD	Time to Smoke Peak, min	Max CO, ppm	Time to Max CO, min	t_i, Obs, min	t_d, Obs, min
13-16-1 (Kapton)										
NF	550	0.7497	0.370	2.55	0.02	4.8	7280	10.2	12.0	15.5
									11.8	15.1
									12.4	15.4
NF	550	0.7489	0.300	3.20	0.02	4.9	5770	10.2	13.4	17.4
									13.3	17.0
									12.9	22.6
NF	600	0.7511	0.751	1.99	0.04	6.4	26600	19.6	8.6	10.3
							(15000 @	10.5)	8.3	10.5
									8.8	10.4
NF	700	0.9998	0.711	1.06	0.05	3.5	12625	8.3	5.2	7.5
									5.4	7.7
									5.4	7.7
F	700	1.0001	0.726	1.03	0.02	0.7	6380	6.4	6.8	10.7
									7.5	11.6
									6.8	10.4
F	850	1.0009	0.931	0.38	0.10	0.5	175	0.8	19.4	S†
									19.4	S
									19.4	S

† S = Survived 14 days.
∫ F = Flaming; NF = Nonflaming.

TABLE B-1. PRELIMINARY TESTS--Continued

Mode ∫	Temp, °C	Sample Wt, g	Sample Loss, g	Time to Visible Smoke, min	Max Smoke Dendisty, OD	Time to Smoke Peak, min	Max CO, ppm	Time to Max CO, min	t_i, Obs, min	t_d, Obs, min
1-16-1 (Silicone Rubber/Polyolefin)										
NF	550	0.7504	0.281	0.60	0.14	2.2	3232	6.4	29.8	S†
									NI ‡	S
									30.7	S
F	550	2.5005	0.960	0.88	0.10	2.5	3592	6.4	13.0	S
									13.4	29.8
									12.7	S
NF	575	0.9990	0.375	0.61	0.24	2.3	3000	8.3	15.0	31.1
									15.4	44.7
									16.8	30.1
F	600	0.7519	0.282	0.52	0.05	1.2	1380	4.6	NI	S
									NI	S
									NI	S
F	650	0.7501	0.300	0.57	0.06	1.1	1112	6.4	NI	S
									NI	S
									NI	S

†S = Survived 14 days.
‡NI = Not incapacitated.
∫NF = Nonflaming.

TABLE B-1. PRELIMINARY TESTS--Continued

Mode[∫]	Temp, °C	Sample Wt, g	Sample Loss, g	Time to Visible Smoke, min	Max Smoke Density, OD	Time to Smoke Peak, min	Max CO, ppm	Time to Max CO, min	t_i, Obs, min	t_d, Obs, min
12-20-2 (Teflon)										
NF	550	1.0078	1.008	3.22	0.10	4.8	682	10.2	17.1	38.3
									26.9	30.3
									20.0	40.8
NF	550	1.0022	0.942	2.79	0.13	4.8	885	10.2	13.3	1D*
									13.6	1D
									13.7	1D
NF	600	1.0005	0.992	1.95	0.27	3.8	1014	8.3	18.3	4H▽
									18.0	4H
									17.9	31
NF	700	1.0014	1.001	1.39	0.10	2.8	469	4.6	5.6	13.1
									5.5	10.9
									7.3	23.3
F	700	1.000	1.000	0.90	0.10	2.6	2580	8.3	9.3	13.1
									8.9	11.1
									9.4	22.4
F	700	1.0019	1.002	1.19	0.16	2.8	1415	2.7	12.2	29.8
									10.6	14.6
									11.3	32
F	700	1.0014	1.001	1.05	0.17	2.3	1239	2.7	6.7	36
									6.4	27.5
									7.3	36
F	700	1.0000	1.000	1.48	0.19	2.8	1415	8.3	11.0	29.0
									10.5	18.8
									10.7	15.1
F	700	1.0008	1.001	1.19	0.21	3.0	366	4.6	14.6	40
									14.4	40
									15.1	90

[∫] F = Flaming, NF = Nonflaming.
* D = Days survived.
▽ H = Hours survived.

TABLE B-1. PRELIMINARY TESTS--Continued

Mode[∫]	Temp, °C	Sample Wt, g	Sample Loss, g	Time to Visible Smoke, min	Max Smoke Density, OD	Time to Smoke Peak, min	Max CO, ppm	Time to Max CO, min	t_i, Obs, min	t_d, Obs, min
3-20-1 (Tefzel)										
NF	550	0.7510	0.741	1.32	0.22	2.5	8360	10.2	7.4	10.9
									7.6	11.0
									7.7	11.4
F	550	0.7500	0.750	1.59	0.15	2.5	7050	10.2	10.6	14.5
									11.2	15.6
									10.9	12.4
NF	600	0.7513	0.741	1.30	0.24	2.4	7240	10.2	6.5	11.6
									6.4	12.7
									6.3	11.4
A3-7X14-2										
NF	750	1.0009	0.798	0.48	0.50	1.3	10433	4.6	7.4	9.6
									7.2	9.7
									7.2	9.6
A5-00-3										
F	500	1.0020	0.661	1.61	0.27	3.4	3593	10.2	14.8	S[†]
									12.3	20.7
									13.1	21.7
F	550	1.0035	0.659	1.20	0.26	2.8	4895	8.3	10.0	17.4
									10.3	21.8
									10.8	19.0
F	550	1.0027	0.658	1.30	0.12	2.8	4450	8.3	13.3	25.4
									12.1	18.4
									13.8	19.6

∫ F = Flaming, NF = Nonflaming.
† S = Survived 14 days.

TABLE B-1. PRELIMINARY TESTS--Continued

Mode[∫]	Temp, °C	Sample Wt, g	Sample Loss, g	Time to Visible Smoke, min	Max Smoke Density, OD	Time to Smoke Peak, min	Max CO, ppm	Time to Max CO, min	t_i, Obs, min	t_d, Obs, min
A5-14-1										
NF	750	1.0016	0.582	0.35	0.32	1.3	10628	8.3	7.1	8.8
									6.8	9.3
									6.8	8.4
A7-24X19-5										
F	550	0.9980	0.844	0.93	0.18	2.4	5231	4.6	11.2	15.1
									11.1	26.3
									13.2	26.8
F	550	1.0007	0.848	0.72	0.38	2.8	5834	4.6	7.9	11.2
									7.5	10.8
									8.2	13.4
A2-6/2X19-4										
F	550	1.0003	0.998	1.19	0.45	2.4	6894	4.6	7.9	11.9
									8.9	12.3
									8.4	14.4
F	550	1.0010	0.997	1.35	0.46	2.8	7727	4.6	6.8	12.3
									7.4	12.2
									6.7	11.9

[∫] F = Flaming, NF = Nonflaming.

APPENDIX C
ANIMAL MORTALITY

TABLE C-1. EXPERIMENTAL ANIMAL MORTALITY

Material	Thermal* Condition	Observed Mortality† 30-min	14-day	Comments
12-20-2 (Teflon)	LTNF	5/9	9/9	Deaths at 45, 120, & 120 min, and at 2 days
	LTF	3/12	9/12	Deaths at 33.2, 39.4, 37, 200, & 200 minutes, and 1 day; 3 survivors
	HTF	7/12	12/12	Deaths at 34, 35, 36, 37, and 45 minutes
1-16-1 (Silicone/PO)	LTNF	1/9	4/9	Deaths at 32.1, 36, and 38.2 minutes; 5 survivors
	LTF	0/6	0/6	All animals survived
	HTF	0/9	0/9	All animals survived
3-20-1 (Tefzel)	LTNF	9/9	9/9	
	LTF	9/9	9/9	
	HTF	8/9	9/9	One death at 30.5 minutes
13-16-1 (Kapton)	LTNF	9/9	9/9	
	LTF	9/9	9/9	
	HTF	9/9	9/9	
11-20-1 (Exane)	LTNF	6/9	9/9	Deaths at 1, 1, and 2 days
	LTF	7/9	9/9	Deaths at 30.3 and 34 minutes
	HTF	9/9	9/9	
12-12-4 (Halar)	LTNF	9/9	9/9	
	750F	9/9	9/9	
	750NF	9/9	9/9	
A1-14-1(PVC)	LTNF	1/9	3/9	Deaths at 3 and 4 days
	LTF	6/9	9/9	Deaths at 30.2, 33, and 36 minutes
	HTF	9/9	9/9	

*†See footnotes at end of table, p. 83.

TABLE C-1. EXPERIMENTAL ANIMAL MORTALITY--Continued

Material	Thermal* Condition	Observed Mortality† 30-min	14-day	Comments
A7-00-2	LTNF	9/9	9/9	
	LTF	8/9	9/9	One death at 30.1 minutes
	HTF	9/9	9/9	
A3-7X14-2	LTNF	9/9	9/9	
	LTF	9/9	9/9	
	HTF	9/9	9/9	
A5-00-3	LTNF	8/9	9/9	One death at 31.0 minutes
	LTF	3/9	6/9	Deaths at 34, 35, and 39 minutes; 3 survivors
	HTF	9/9	9/9	
A5-14-1	LTNF	9/9	9/9	
	LTF	7/9	7/9	Two survivors
	HTF	9/9	9/9	
A6-4X12-1	LTNF	5/9	9/9	Deaths at 34, 36, and 36 minutes, and at 3 days
	LTF	0/9	0/9	All animals survived
	HTF	0/9	0/9	All animals survived
A7-24X19-5	LTNF	9/9	9/9	
	LTF	8/9	8/9	One animal survived
	HTF	9/9	9/9	
A2-6/2X19-4	LTNF	9/9	9/9	
	LTF	9/9	9/9	
	HTF	9/9	9/9	

* Thermal Condition: LTNF = low-temperature nonflaming; LTF = low-temperature flaming; HTF = high-temperature flaming; 750F= 750°C, flaming; 750NF = 750°C, nonflaming.

† Observed mortality is presented as the ratio of observed deaths within the designated time to the total number of experimental animals exposed in that mode.

APPENDIX D

TECHNIQUES FOR COMPARISONS OF TOXIC HAZARDS

The laboratory evaluation of material toxicity has generally been based on animal response to a unit weight of sample. For most polymers, this would be a logical and unbiased basis for evaluation provided that animal response times were a function of the concentrations of toxic gases produced, and they in turn were proportional to the weight of polymer decomposed.

For wiring insulation, toxicity evaluation would also be logically based on material weight. The weight of insulation required for a specific conductor, however, will vary with the diameter of that conductor, as well as with the insulation's dielectric properties, abrasion and heat resistance, etc. When two or more conductors are considered for the same application, the same length of conductor will be required regardless of the nature of its insulation. Therefore, the relative potential toxicities of conductors might be more meaningfully compared if expressed as animal response times normalized for the weight of insulation on a unit length of conductor.

Our approach to this problem was (i) to test all insulation materials at the same sample weight, selected to obtain response times within 30 min, and (ii) to arithmetically normalize the experimental animal response times to the response times that theoretically would be produced by decomposing the weight of insulation from one meter of conductor. The normalization is based on the assumption that toxicity ($1/t_r$) is directly proportional to the weight of insulation decomposed.

The general form of the normalizing equation is

$$t'_r = \frac{t_r \cdot a \cdot b}{100}, \qquad (1)$$

where t'_r = response time normalized for the weight of insulation from 1 meter of conductor, in minutes.

t_r = experimentally determined response time for 1 gram of insulation in which each component is in proportion to its percent of the total insulation weight (e.g., Std t_r), in minutes.

a = length of sample assembly, in centimeters, equal to 1 gram of insulation (determined by physically stripping the insulation from a measured length of sample assembly and weighing the insulation, a = cm assembly/g insulation.

b = number of conductors in sample assembly.

100 = conversion factor, 100 cm/m.

In general, t_r' can be calculated for any sample assembly for which t_r has been experimentally determined and for which a and b are known. Also, t_r' can be calculated for sample assemblies for which t_r has not been experimentally determined if all of the following conditions are met:

1. t_r for a different size conductor having the same kind of insulation has been determined.

2. The insulation must be homogeneous or of constant cross-sectional composition.

3. The values for a and b are known (or can be determined).

For heterogeneous insulation materials, or insulations with a nonconstant cross-sectional composition for different sizes of conductor, a valid t_r' cannot be calculated from t_r for a different size conductor. In this case, the experimentally determined t_r (for a 1-g sample) would be different for insulations taken from different conductor sizes. The only case where t_r values can be used to calculate t_r' for a different conductor size is the case where insulation samples taken from both conductors would be of identical weight percent composition.

Comparison of the relative potential toxicities of wiring sample assemblies can be made on the basis of equal lengths of conductors for all assemblies for which a valid t_r' can be calculated. The material with the largest t_r' value is the least toxic, that with the smallest t_r', most toxic. The calculation of t_r' is illustrated in the following examples. The animal response time (t_r) selected for these comparisons is the Std t_i.

EXAMPLE 1. SAME SIZE AND NUMBER OF CONDUCTORS, DIFFERENT INSULATIONS

Two 12AWG single-conductor assemblies, with different insulation types, were considered as candidates for a particular installation. Test results gave Std t_i's and physical parameters as shown below.

Sample Assembly	AWG	No. Conductors in Assembly	Length of Conductor per gram of Insulation, cm/g	Std t_i, min
A	12	1	0.80	18
B	12	1	0.15	20

For assembly (A), $t_i' = \frac{(t_i)\ (a)\ (b)}{100} = \frac{(18)(0.80)(1)}{100} = 0.14$ min

For assembly (B), $t_i' = \frac{(20)(0.15)(1)}{100} = 0.03$ min

Therefore, assembly (A), on an equal end-use (equal-length) basis, had a calculated t_i' 4.7 times greater than assembly (B) (0.14/0.03 = 4.7), although the experimental t_i's indicated that assembly (A) was slightly more toxic (shorter t_i) per gram of insulation. The greater weight of insulation per unit length of conductor found in assembly (B) more than offset its slight toxicity advantage (on an equal-weight basis) when equal lengths of each assembly were compared.

EXAMPLE 2. DIFFERENT SIZE CONDUCTORS, SAME NUMBER OF CONDUCTORS, SAME INSULATION

An experimentally determined t_i was available for one (A) of two single-conductor assemblies being considered for a design application requiring 12AWG wire. The other assembly (B), a single conductor with a single-component insulation, had been tested for a 16AWG wire size (B-16AWG) having insulation identical to (B). The weight of insulation per unit length of conductor was determined empirically for assembly (B). The following information was available.

Sample Assembly	AWG	No. Conductors in Assembly	Length of Conductor per gram of Insulation, cm/g	Std t_i, min
A	12	1	12	4.5
B	12	1	11	(unknown)
B-16AWG	16	1	8	4.0

For assembly (A), $t_i' = \frac{(4.5)(12)(1)}{100} = 0.54$ min

To calculate t_i' for assembly (B), we use the Std t_i for assembly (B-16AWG) (which has identical insulation) and the empirically determined value for length of conductor per gram of insulation for assembly (B).

For assembly (B), $t_i' = \frac{(4.0)(11)(1)}{100} = 0.44$ min.

Thus the slight toxicological advantage of assembly (A) (t_i' = 0.54 min) over assembly (B)(t_i' = 0.44 min) was determined without actually testing the insulation from assembly (B) in the chamber.

EXAMPLE 3. SAME SIZE CONDUCTORS, DIFFERENT NUMBER OF CONDUCTORS PER ASSEMBLY, DIFFERENT INSULATIONS

In a proposed application, a 4-conductor assembly (A) was considered as a replacement for four single conductor assemblies (B). The relative toxic

hazard incurred by making this substitution was assessed by calculating the t_i for the materials from the experimental data below.

Sample Assembly	AWG	No. Conductors in Assembly	Length of Conductor per gram of Insulation cm/g	Std t_i, min
A	12	4	0.80	18
B	12	1	12	4.7

For assembly A (4-conductor), $t_i' = \frac{(18)(0.80)(4)}{100} = 0.58$ min

For assembly B (1-conductor), $t_i' = \frac{(4.7)(12)(1)}{100} = 0.56$ min

In this example, the toxicological advantage of substituting the 4-conductor assembly (A, $t_i' = 0.58$ min) for four single conductor assemblies (B, $t_i' = 0.56$ min) would be negligible. Note that because Equation (1) defines t_r' as the response time for 1 meter of conductor, the t_i' values calculated above represent equivalent lengths of the two assemblies in the ratios that they would be used, i.e., 4 meters of single conductor assembly (B): 1 meter of 4-conductor assembly (A).

If the response time for 1 meter of the 4-conductor assembly (A) were required, it could be calculated by considering the assembly as a single conductor and using a value of (1) for the variable (b) (number of conductors in assembly) of Equation (1).

EXAMPLE 4. DIFFERENT SIZE AND NUMBER OF CONDUCTORS, SAME INSULATION

The need for an additional conductor in a limited space installation prompted the substitution of a 5-conductor, 16AWG assembly (B) for the existing 4-conductor, 16AWG assembly (A). The experimental t_i was available for assembly A and for a 12AWG, 3-conductor assembly (C) insulated with the same single component insulation as assembly (B). The available experimental data are listed below.

Sample Assembly	AWG	No. of Conductors in Assembly	Length of Conductor per gram of Insulation, cm/g	Std t_i, min
A	16	4	0.80	18
B	16	5	0.52	(unknown)
C	12	3	0.75	20

For assembly (A), $t_i' = \frac{(18)(0.80)(4)}{100} = 0.58$ min

To calculate t_i' for assembly (B), we use the experimental t_i from assembly (C) (same insulation) and the length of conductor per gram of insulation and number of conductors from assembly (B) (for a and b respectively in Equation (1)).

For assembly (B), $t_i' = \frac{(20)(0.52)(5)}{100} = 0.52$ min

Thus assembly (B) has a slightly shorter t_i' (more toxic) than assembly (A) per conductor.

Since, in this case, a 5-conductor assembly is being substituted for a 4-conductor assembly, it would appear desirable to look at the relative toxic hazard per assembly length. This response time is calculated as described in Example 3, i.e., consider the assembly to be a single conductor using a value of 1 for b in Equation (1). Then

For assembly (A), response time for 1 meter of assembly =

$$\frac{(18)(0.80)(1)}{100} = 0.14 \text{ min}$$

For assembly (B), response time for 1 meter of assembly =

$$\frac{(20)(0.52)(1)}{100} = 0.10 \text{ min}$$

Thus assembly (B) presents a slightly greater toxic hazard than assembly (A) on the basis of per-unit-length of assembly, as well as per-unit-length of conductor, (t_i').

EXAMPLE 5. DIFFERENT SIZE AND NUMBER OF CONDUCTORS, DIFFERENT INSULATION

In a situation similar to that described in Example 4, a 5-conductor, 16AWG assembly (B) was to be used as a replacement for an existing 4-conductor, 16AWG assembly (A). The experimental t_i was available for assembly (A) and for a 3-conductor, 12AWG assembly (C) having a multicomponent insulation similar to the insulation on assembly (B) but of variable cross-sectional composition (variable weight-percent of each component) when applied to different sizes of conductors. The available data for these assemblies are shown below.

Sample Assembly	AWG	No. of Conductors in Assembly	Length of Conductor per gram of Insulation, cm/g	Std t_i, min
A	16	4	0.80	18
B	16	5	0.45	(unknown)
C	12	3	0.87	22

While it might first appear that t_i' for assembly (B) could be calculated as described in Example 4 using, in Equation (1), the t_i from assembly (C) and a and b from assembly (B), such a calculation would not be valid in this case. The insulations on assemblies (B) and (C) are variable in percent composition when applied to different sizes of conductors (e.g., for 12AWG wire, component 1 = 60%, component 2 = 40%, for 16AWG wire, component 1 = 67%, component 2 = 33% by weight). Therefore, t_i's obtained from 1 gram of each insulation would be different. Consequently, the only way that a relative potential toxicity comparison could be made between assemblies (A) and (B) would be to first determine t_i for assembly (B) experimentally and then to calculate t_i' for assembly (B) on the basis of that test. Adequate information was given for calculation of the respective t_i' for assembly (A).

REFERENCES

1. Crane, C. R., D. C. Sanders, B. R. Endecott, J. K. Abbott, and P. W. Smith: Inhalation Toxicology: I. Design of a Small-Animal Test System II. Determination of the Relative Toxic Hazards of 75 Aircraft Cabin Materials, Office of Aviation Medicine Report No. FAA-AM-77-9, 1977.

2. Guyton, A. C.: Measurement of the Respiratory Volumes of Laboratory Animals, AM. J. PHYSIOL., 150:70-77, 1947.

3. Anderson, R. C. and Y. C. Alarie: Screening Procedure to Recognize "Supertoxic" Decomposition Products from Polymeric Materials under Thermal Stress, J. COMB. TOX., 5:54-63, 1978.

4. Hilado, C. J., H. J. Cumming, A. M. Machado, J. E. Schneider, C. R. Crane, D. C. Sanders, B. R. Endecott, and J. K. Abbott: Comparison of Animal Responses to the Combustion Products Generated by Two Test Procedures, the USF/NASA Methodology and the FAA/CAMI System, J. COMB. TOX., 4:325-359, 1977.

5. Kimmerle, G.: Aspects and Methodology for the Evaluation of Toxicological Parameters during Fire Response, J. FIRE FLAM/ COMB. TOX., 1:4, 1974.

6. Birky, M. M., I. N. Einhorn, N. L. Grunnett, S. C. Packham, J. H. Petajon, and J. D. Seader: Physiological and Toxicological Effects of the Products of Thermal Decomposition from Polymeric Materials, NBS SPECIAL PUBLICATION 411:105-124, November 1974.

7. Potts, W. J. and T. S. Lederer: A Method for Comparative Testing of Smoke Toxicity, J. COMB. TOX. 4:114-162, 1977.

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